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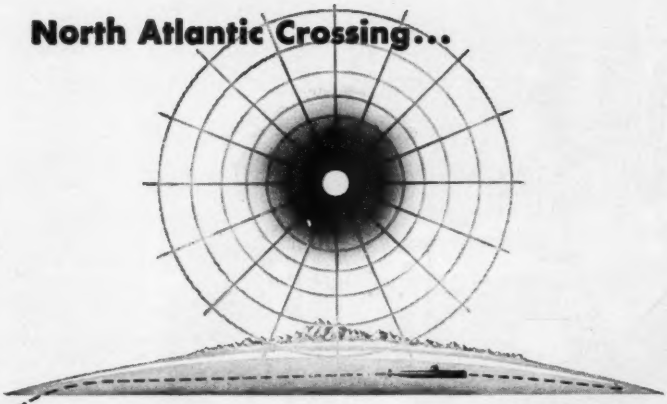

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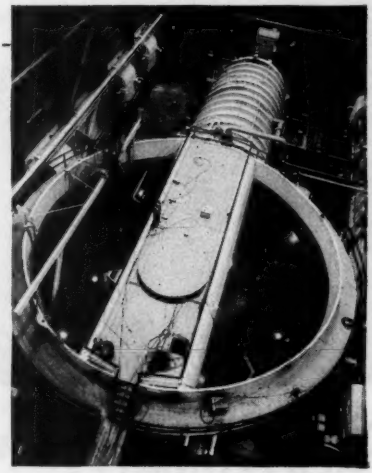

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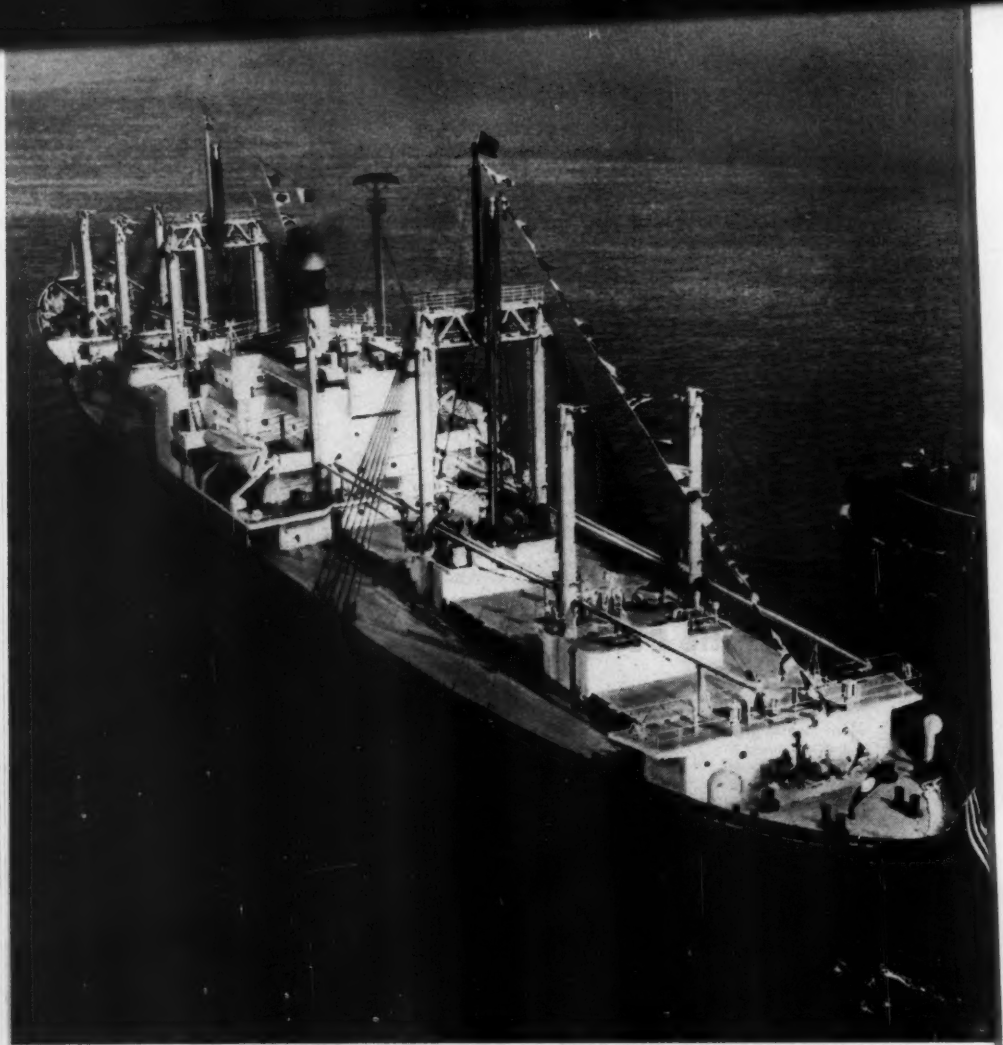

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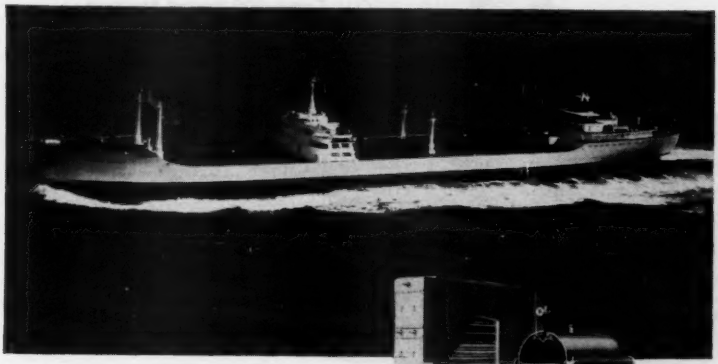

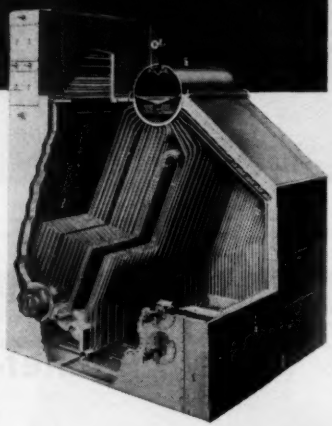

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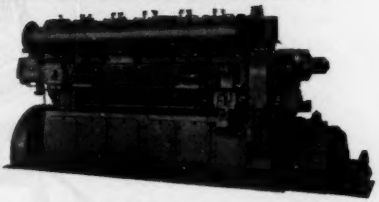

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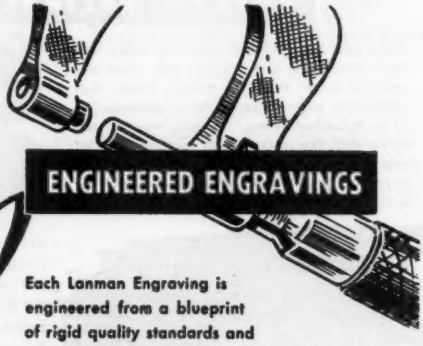

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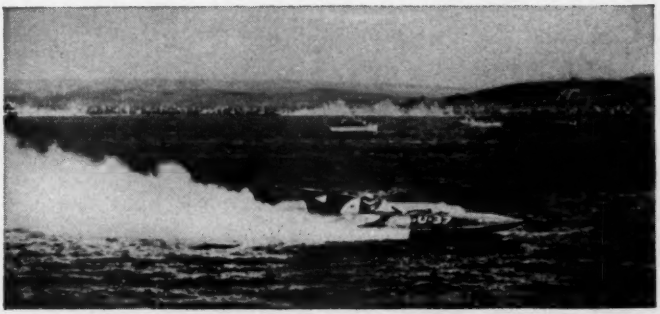

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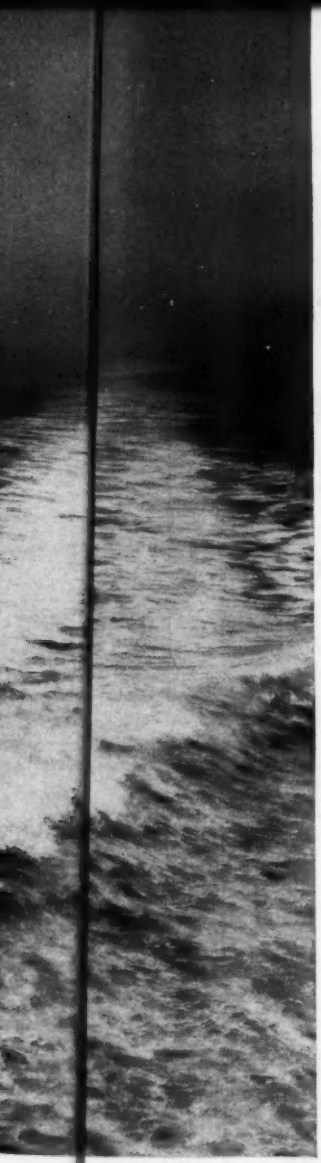

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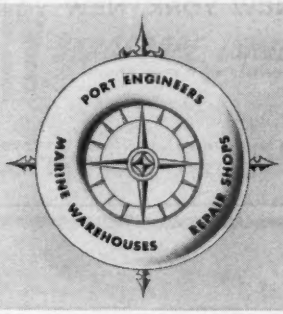

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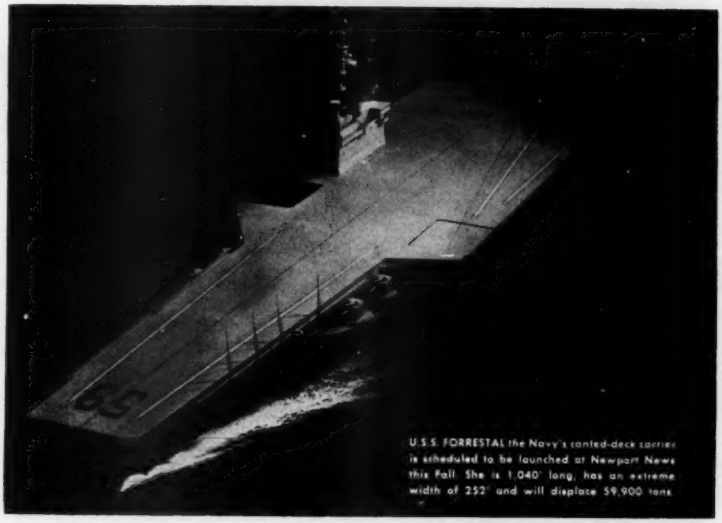
Designers and manufacturers of radio communication and navigation equipment for the Armed Forces.



U.S.S. FORRESTAL the Navy's canted-deck carrier is scheduled to be launched at Newport News this Fall. She is 1,040' long, has an extreme width of 252' and will displace 59,900 tons.

Greatest of the "Fighting Ladies"

The U. S. S. FORRESTAL

Construction of the U.S.S. FORRESTAL is one more achievement which affirms that outstanding ships are the tradition of Newport News.

As the lead yard in designing and developing all of the basic classes of carriers, Newport News plays an important role . . . *builders of great ships to help keep America strong on the seas.*

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Aircraft Carriers built by
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RANGER	2-25-33
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HORNET	8-30-43
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TICONDEROGA	2-7-44
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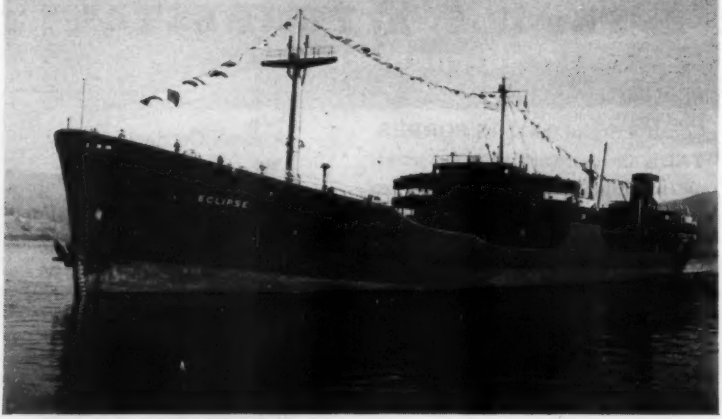
provides 14,850 shp for SS Eclipse

A De Laval cross-compound, double reduction geared turbine powers the Socony-Vacuum Oil Company's new 25,000 ton tanker "ECLIPSE" built by the Sun Shipbuilding and Dry Dock Company • This De Laval unit has a maximum continuous capacity of 14,850 shp at a propeller speed of about 103 rpm. For years, fleet operators have looked to De Laval for dependable, precision-made marine equipment to power passenger and cargo ships, tankers, ore carriers and many other types of vessels.



DE LAVAL *Marine Division*

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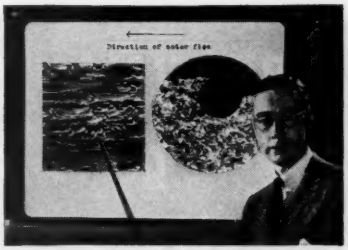
AIR BUBBLES:

what causes them, how they affect condenser tubes

Before corrosion can occur, oxygen from the air dissolved in cooling waters must be present. But normally its presence doesn't cause *rapid* corrosion of condenser tubes.

What can cause rapid corrosion is air in the form of bubbles where turbulent flow is present. Whirlpools in the intake tunnel, leaky packing glands on pumps and at projections in injection pipes or water boxes may produce air bubbles of harmful size. Any condition that will produce a negative pressure at some point along the tube, such as a long outlet leg from a condenser, can cause air bubbles. Local pitting may then occur rapidly.

Publication B-2, "Anaconda Tubes and Plates for Condensers and Heat Exchangers," discusses *all* the important operational factors, and gives much other useful information. And,



Left, impingement corrosion of Admiralty tube by high velocity sea water with air bubbles. Right, section through part of horseshoe-shaped pit.

of course, our Technical Department stands ready to assist you in the selection of tube alloys from our extensive line. *The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.* 54105A

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Tubes and Plates for Condensers and Heat Exchangers

Arsenical Admiralty-439; Ambraloy-927*; Cupro Nickel, 30%-702; and other copper alloys.
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Preferred through two World Wars for their dependability under difficult loads and speeds.

Each ship of "Missouri" Class has 36 Kingsbury Bearings, including the four main thrusts.

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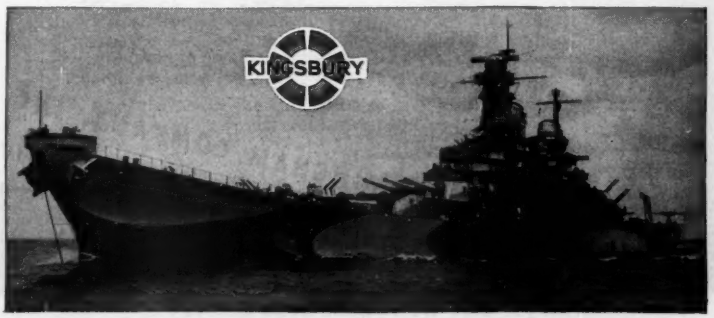

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gives smoothness to
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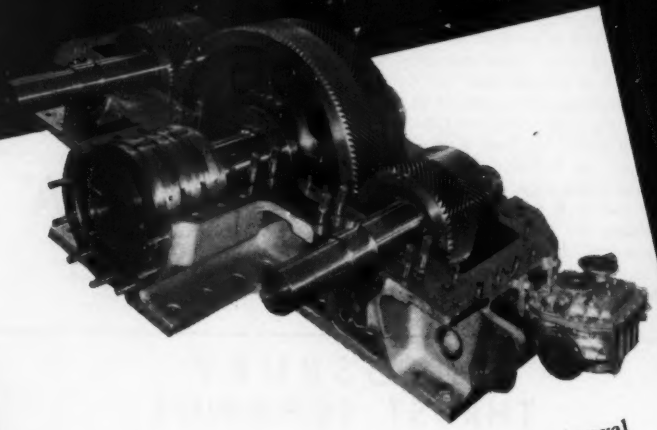

Farrel propulsion gears, used in a wide variety of naval vessels, are precision generated by the Farrel-Sykes gear generator. Accuracy of tooth spacing, profile and helix angle, and other qualities inherent in the Farrel-Sykes method of gear generation assure smooth, quiet and efficient operation throughout a long service life.

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You can't. Of course, you may think *this* race is not particularly important so why exert yourself?

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And, right now, the United States Merchant Marine needs nothing so much as interested and active rooters.

The Babcock & Wilcox Company, which has helped to power so many thousands of American ships, is continuing to work in the tradition of engineering excellence which has made the U.S.A. the world's leader in the design and construction of merchant and naval vessels.

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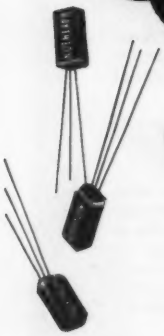

Transistors by the bushel from Raytheon

It's true. Raytheon, first to mass-produce junction transistors, has already made over *one million* of these Tom Thumb units – more than all other companies combined!

This leadership in designing and producing transistors, as well as semi-conductor diodes, special purpose tubes, "Reliable" miniature and subminiature tubes, nucleonic tubes, receiving tubes, cathode ray tubes, klystrons and magnetrons, is the big reason why so many important new developments *depend* on Raytheon.

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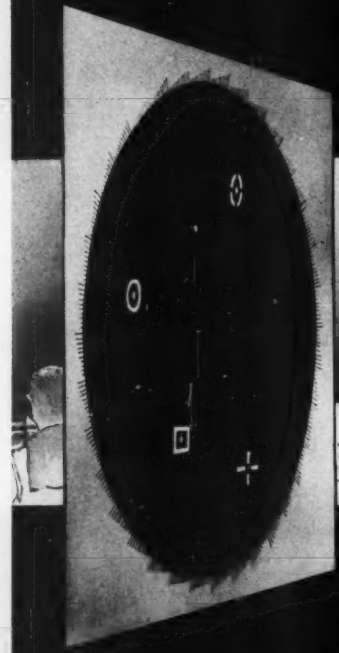
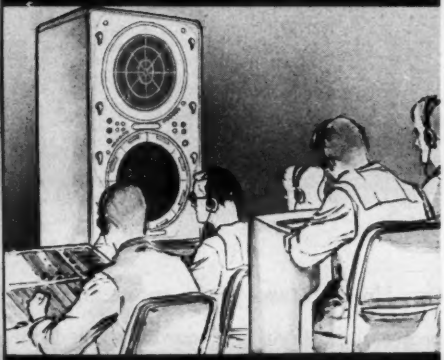
MARKED . . .

FOR DESTRUCTION!

In a matter of seconds, these oncoming enemy blips will be marked for destruction.

When the Navy's new Mark 6 Target Designation System "sights" an enemy, the range and bearing data are automatically transmitted to appropriate gun directors. Guns are "on target" before the flying object gets within maximum effective range. The result may well spell the difference between survival and disaster to ship and crew.





Developed by RCA in close coordination with Naval personnel, the Mark 6 Target Designation System is now in full production. It is but one of the many complete electronic systems which RCA has developed for the armed forces. RCA engineering—from original planning to final production—assures greater efficiency, effectiveness and safety in operation.

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Terry Marine Turbines are dependable, compact, efficient machines especially designed for driving generators, boiler feed pumps, fuel oil pumps, compressors, etc. aboard ship. They offer the advantages of over fifty years experience in the Marine Field on both Commercial and Naval Vessels.

Turbines ranging from 5 to 3000 H.P. are built in the Terry Solid Wheel design as well as in the Axial Flow, single stage and multistage types.

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U.S.S. BARTON DD722
DELIVERED DEC. 30, 1943 L.O.A. 376'

U.S.S. FRANK KNOX DD742
DELIVERED DEC. 6, 1944 L.O.A. 390'

LST 1156
DELIVERED NOV. 21, 1952 L.O.A. 384'

U.S.S. MITSCHER DL2
DELIVERED MAY 9, 1953 L.O.A. 493'

U.S.S. DEALEY DE1006
DELIVERED MAY 28, 1954 L.O.A. 314'

Some Bath built ships which were first in their class delivered to the United States Navy.

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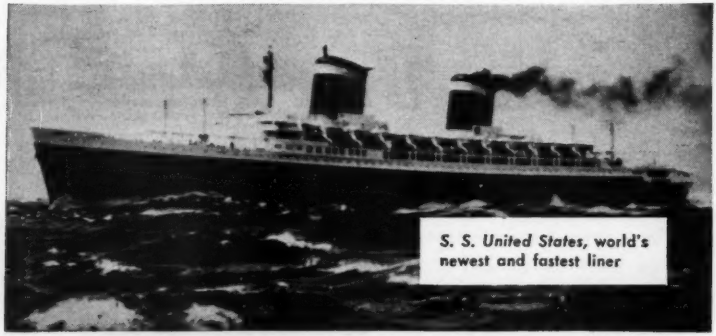

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Allis-Chalmers equipment sailed the globe on all types of craft in World War II and continues in action with today's fleet. In addition to the products mentioned above, newly developed equipment will greatly improve tomorrow's fleet, on and below the surface.

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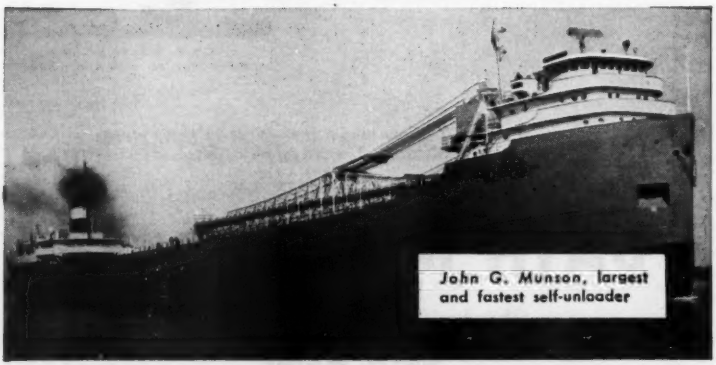

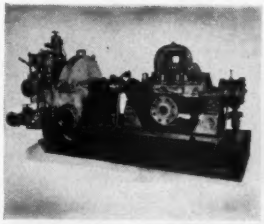
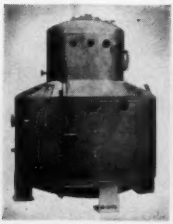
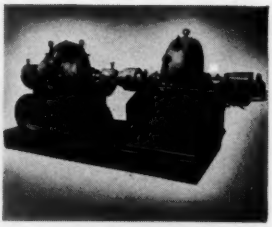

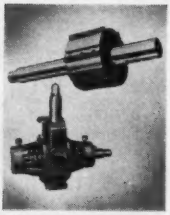
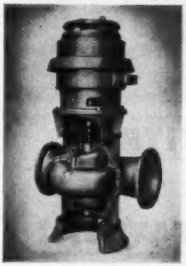
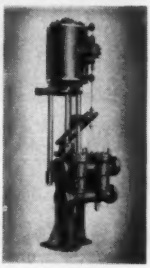
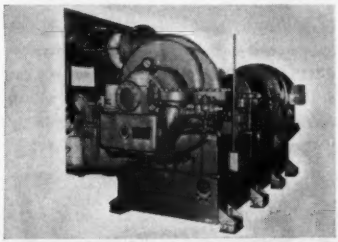
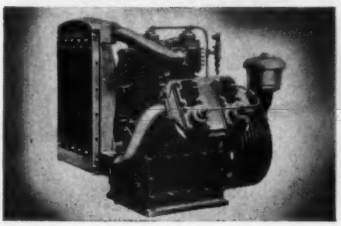

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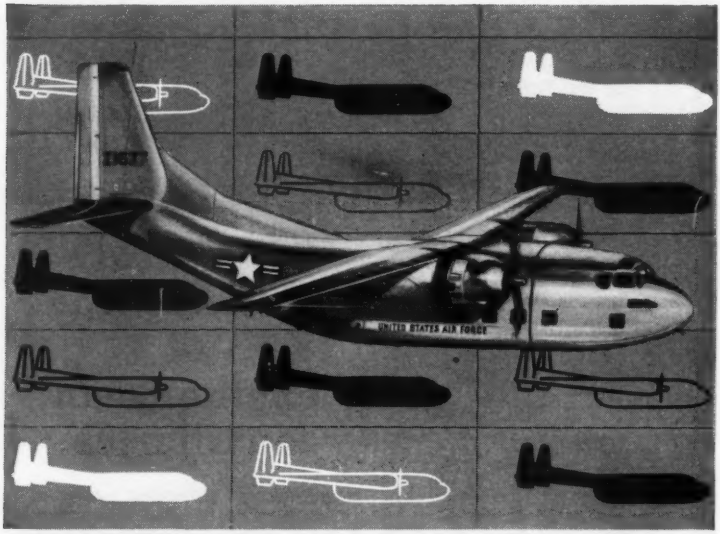

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Continuing quantity production of the combat proven C-119 Flying Boxcar assures the nation that our military transport program is completely flexible. This dual production brings closer the day when C-123's and C-119's will be in regular use as a part of the U. S. Air Force and U. S. Army military operations.

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I hereby apply for membership in the U. S. Naval Institute and enclose $3.00 in payment of dues for the first year to begin with the .....issue of the PROCEEDING (the monthly magazine of the U. S. Naval Institute).

I am interested in the objects and purposes of the Institute, namely, the advancement of professional, literary, and scientific knowledge in the Navy. I am a citizen of .....and understand that members are liable for dues until the date of receipt of their written resignations.

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JOURNAL

OF

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

VOL. 66. NOVEMBER 1954. No. 4

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The Society as a body is not responsible for statements made by individual members

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Captain T. H. White, U. S. N.
Captain J. E. Hamilton, U.S.N., (Ret.), Secretary-Treasurer

SECRETARY'S NOTES

COUNCIL MEETING

A meeting of the Council of the Society was held on 8 September 1954 to consider general business. Matters considered were:

Council Members

Because of official transfer from the Washington area, two members of the Council had submitted their resignations. Successors were appointed as follows:

Captain H. M. Heiser, U.S.N. to complete the term, expiring on 31 December 1955 of

Captain L. V. Honsinger, U.S.N.

Captain T. H. White, U.S.N. to complete the term, expiring on 31 December 1954 of

Captain G. M. Chambers, U.S.N.

PRINTING OF THE JOURNAL

The last two issues of the JOURNAL have been printed by the Benson Printing Co., of Nashville, Tennessee. The Editor reported that the operation with an out of town printer had proven to be practicable. He also stated that the quality of the printing appeared to be satisfactory and no adverse comments had been received. Members of the Council agreed as to the quality. The cost of the two issues had been appreciably less than previous printing. The Council authorized the Editor to enter into an agreement for the continued printing of the JOURNAL by the Benson Printing Co. This has been done and should provide price and quality protection to the Society for the next ten issues (the term of the agreement).

SOCIETY FINANCES

The present and near future financial position of the Society is very good. Long term planning is difficult because of the uncertainty of the future renewal of the contract by which the Bureau of Ships furnishes copies of the JOURNAL to major ships and stations. This subscription is of long standing but an erroneous impression exists in some quarters that it is a "supporting" subscription in the nature of a subsidy. This is entirely incorrect but naturally the effect of loss of the subscription, which would reduce the circulation of the JOURNAL by more than 20 per cent, would increase the cost of printing per copy appreciably. Failure to renew the contract will require some budget adjustments. Hence, the Council decided that it would be unwise to make any reductions in membership dues, advertising rates, or subscription price at this time, even though (except for the uncertainty regarding the subscription) the financial condition of the Society might warrant such reductions.

The Council did decide to increase expenditures by authorizing an increase in remuneration to authors by increasing the rate from $40.00 to $150.00 to $50.00 to $250.00 which is estimated to increase annual expenses by $2,000.00; and an increase in the salaries account of $1,800.00 per year.

ANNUAL MEETING

The annual meeting of the Society was held in Washington, D. C. on Tuesday, 5 October 1954.

MEMBERSHIP

The following information of changes in membership were placed before the members at this meeting:

MEMBERS

MEMBERSHIP on 1 January, 1945 thru 1 January, 1954, and on 1 October 1954.

	Naval	Civil	Associate	Total
1945	1022	552	346	1920
1946	1328	580	364	2272
1947	1595	627	386	2608
1948	1651	654	414	2719
1949	1606	700	413	2719
1950	1581	800	405	2786
1951	1416	836	380	2632
1952	1374	889	383	2646
1953	1396	933	396	2725
1954	1410	987	404	2801
Joined 1 Jan. to 1 Oct. 1954	54	78	41	173

There is indication from these figures that a membership drive might be effective. Such drives in the past have not been too productive because the limited clerical staff employed by the Society does not have the capacity to initiate and maintain a sustained mail campaign. Appeals to members to produce additional members have not been too productive.

FINANCES

The action of the Council. mentioned above was based on the following predictions of financial status which were submitted to the annual meeting:

INCOME	1953*	1954	1955[1]	1955[2]
Dues	$22,535.14	23,500.00	25,000.00	25,000.00
Advertising	7,125.00	7,000.00	7,000.00	7,000.00
Sales	318.47	1,000.00	1,000.00	1,000.00
Subscriptions	16,051.00	14,500.00	13,000.00	8,000.00
Interest	1,500.00	1,500.00	1,500.00	1,500.00
Banquet	2,041.41	2,124.03	2,000.00	2,000.00
Total	$49,571.02	$49,624.03	$49,500.00	$44,500.00
EXPENDITURES				
Printing	$28,733.09	24,000.00	20,000.00	19,000.00
Engraving	1,710.32	1,800.00	1,600.00	1,600.00
Manuscript	3,160.00	3,165.00	5,000.00	5,000.00
Other Pub. costs	779.28	800.00	800.00	800.00
Salaries	8,700.00	10,200.00	11,400.00	11,400.00
Gen'l. Exp.	3,029.89	2,500.00	2,500.00	2,500.00
Other	1,561.73	1,200.00	1,200.00	1200.,00
Total	$47,674.31	$43,665.00	$42,500.00	$41,500.00
Gain for year	1,896.71	5,959.03	7,000.00	3,000.00
Net Assets End of Year	$62,837.38	$68,796.41	$75,796.41	$71,796.41

[1]If BuShips subscription is renewed. [2]If subscription is not renewed.
*1953 Actual figures.

It is possible that, if a membership drive fails to offset the reduction in circulation if the subscription is dropped, some adjustment in the size of the JOURNAL will be necessary in 1956 to prevent a continuous drop in the value of the net assets. The concensus of the meeting was that no action need be taken at this time.

CHANGE IN BY-LAWS

A change in the by-laws, having been approved previously by the Council, was submitted to the meeting and approved. It will be submitted to the full membership on the ballot for election of officers for 1955. In effect it will read:

"Junior membership: A Junior membership at one-half the dues of regular membership is authorized for undergraduate students at schools to be named under rules to be promulgated by the Council. This membership may be carried during the College years and for the ensuing year at which time it will be dropped unless the junior member transfers to full membership in the appropriate category."

It is contemplated that the Council will name:

The U. S. Naval Academy

U. S. Military Academy

U. S. Air Force Academy

U. S. Coast Guard Academy

U. S. Merchant Marine Academy and

The 52 Naval ROTC colleges for engineering students only.

NOMINATING COMMITTEE

The report of the nominating committee for 1955 was submitted by its chairman, Vice Admiral R. E. McShane, U.S.N., retired, and was approved without modification.

The approved slate which appears on the ballots is:

For President:
Rear Admiral W. D. Leggett, USN

For Secretary-Treasurer:
(1 to be elected)
Captain J. E. Hamilton, USN, Ret.
Captain W. R. Millis, USN, Ret.

For Regular Naval Officer Member of the Council:
(2 to be elected)
Captain Rawson Bennett, USN
Commander W. D. Brincloe, USN
Rear Admiral R. E. Cronin, USN
Captain J. M. Farrin, USN
Rear Admiral F. R. Furth, USN
Captain W. P. Mowatt, USN

For Reserve Officer Member of the Council:
(1 to be elected)
Lieut. Commander J. W. Sawyer, USNR
Captain T. H. Urdahl, USNR

For Civilian Member of the Council:
(1 to be elected)
Mr. T. B. Jacocks
Mr. J. S. Melton

EDITORIAL POLICY

There is believed to be some misunderstanding as to the status of the Society and of its editorial policy as regards its connection with the Department of Defense or one of its Bureaus, namely: The Bureau of Ships.

THE SOCIETY HAS NO CONNECTION WHATEVER WITH ANY PART OF THE FEDERAL GOVERNMENT. It is absolutely a private corporation and its editorial policy is limited only by good taste and by a strong desire to foster free and independent thinking by its authors.

No author expresses any views of the Society. None is authorized nor will be authorized to do so. Also, unless he so specifically states, no author expresses any official views of the organization to which he belongs or by which he is employed.

The Council and editor take no responsibiliy for the engineering (including administrative) soundness of any statement or expression of an author. Publication of an article, in no sense indicates endorsement of the author by anyone except himself. We hold the opinion that an engineering author's reputation rests, in part, on the words which are published under his by-line and that the society's greatest protection, in this regard, lies in the fact that most engineers have a primary interest in the integrity of their own reputations.

If occasionally an article is accepted which may be considered to be unworthy of the engineering profession, this can be charged to a mistake in judgment of the editor plus indifference, on the part of the author, as to his professional reputation. We believe that this lapse is rare. It may happen because of editorial over-zealousness not to be bound by official government policies in engineering matters and to protect the right of full freedom to express personal ideas and technical opinions.

NOTICE

Captain J. C. Broome, RN (Ret.) has undertaken the task of compiling and illustrating some of the more memorable (and printable) signals and dispatches which were transmitted at sea by Allied naval forces during World War II. Publication by an English firm is planned for the near future.

Having served extensively with U. S. forces, Captain Broome feels that no such book will be complete without a proportionate share of material from American files and recollections; and he has turned to the personnel of the U. S. Navy for such help.

Captain Broome, in addition to being an illustrious veteran of the Royal Navy, is a well known cartoonist and illustrator, former managing editor of the magazine *Sketch,* and more recently served as technical director of the highly-successful British film, "The Cruel Sea." He is eminently qualified for the task he has now undertaken.

Accordingly, all hands are requested to forward any pertinent material along the line indicated which they may have, or can recall, to Captain Broome. The only qualifications are that the signal or dispatch was actually sent and is now *un*classified; that the story of the circumstances is reasonably short; and the text of the signal or dispatch be interesting or amusing, or both—in short, that it be *memorable* and *printable!* Credit to the source will be given for all material used.

To expedite, it is suggested that such material be sent to the following address:

Captain John C. Broome, RN (Ret.)
4 Sprimont Place
Chelsea, S.W. 3
Knightsbridge 654, England

IMPROVED INVENTORY MANAGEMENT

A KEY TO IMPROVED FLEET MAINTENANCE

CAPTAIN THOMAS G. REAMY, USN

THE AUTHOR

graduated from the U. S. Naval Academy in 1925, served in battleships and submarines up to December 1941. Commanded USS S-42 and USS *Searaven*. Completed a Post Graduate course in Mechanical Engineering in 1934, receiving M.S. degree in Mechanical Engineering from University of California. He was designated an ED officer in December 1941. Served in BuShips as Machinery Assistant (Diesel) and head of Internal Combustion Engine Section 1942 to 1946, Production Officer, Portsmouth Naval Shipyard 1946 to 1949, Material and Logistics Officer, Staff ComCruDes Pac 1949-1951. In January 1954 he completed a tour of duty as Commanding Officer, Ships Parts Control Center, Mechanicsburg, Pa., and in February 1954 assumed duty as Inspector of Machinery and Naval Inspector of Ordnance, General Electric Company, Schenectady, New York.

The "New Look" has invaded the field of the Navy Supply System. Inventory managers are accumulating surprising facts and figures which open an entirely new vista in the fields of procurement, stocking and distribution of technical materials. The basic data is being forged into highly improved management tools. The same basic data appears capable of being forged into greatly improved maintenance tools.

The outstanding characteristics of the Navy Supply System is the decentralization of control of material on a commodity basis. Each type of material is assigned to one inventory manager. For his particular material, efforts may be concentrated on the peculiarities necessitating different methods of procurement, stocking and distribution. The highly technical materials can thus be managed in a fashion that is not necessary for common use, wholesale consumption commodities. Technical staffs at the control points are therefore composed of specialists in a particular field so that concentration of effort is more easily achieved.

The philosophy of specialization to achieve improved methods of supply can just as easily be applied to improvements in engineering reliability

and maintenance. Until recently the efforts of the inventory managers were of necessity concentrated on the identification and cataloging of their material. This was particularly true at the more technical control points. The program has advanced to the point where efforts are now being shifted to a more intensive study of the activity or velocity of inventory. It is in this field that the "New Look" is in process —A "New Look" that has been christened "Fractionation."

To date "Fractionation" has been confined to the field of supply management. It is the intent of this article to apply it to the engineering field. The data and analysis already compiled by one Supply Demand Control Point is ideal for this purpose. In addition the material under the cognizance of this activity, "The Ships Parts Control Center," encompasses such a wide field of technical material that proposed improvements will have a Navy wide application.

It has been estimated that there is a possible demand for 5 million different items of ship's parts. These run the gamut from five cent items to $500,000 items—from paper gaskets to main propulsion motor armatures — from special screws for food mixers to needles for sewing machines—from steam drums to a one inch mica insulator for a motion picture machine. Manifestly not even a sizable percentage of possible demand can be stocked. Over the years, by various methods, the stock list had grown, by 1951, to some 306,000 items.

In managing this inventory, quarterly reports of stock status on each item were required. These reports showed demand, planned requirements, on hand, dues, obligations and other pertinent data. When consolidated into one usable document the data was then reviewed at the SPCC. Quantities to buy, to distribute and to declare surplus were determined for each item.

Cursory examination of the consolidated reports showed that many items experienced no movement over long periods of time. Accordingly the stock list was divided. Those items showing at least one demand in 21 months were placed on an active list. All other items were classed as inactive. For active items the quarterly reporting cycle was maintained. For items on the inactive list reports were made only when movement occurred. A system for migration from one list to the other was also instituted. The result was a great reduction in "paper washing." More attention could be paid to the "active items."

Replenishment methods were revised. Inactive items were bought only when stocks were exhausted. A new formula was devised for determining requirements for active items. Accurate lead times on an item basis were determined. A vigorous program of surplus disposal was initiated. As the trees were thinned out the forest was discovered. The "active list" was now down to about 150,000 items. But how active was the "active list"?

In early 1952 a page was taken from the methods of the super-market operators. A "best seller" list was compiled. The results were eye opening. At the first look only 60% of the active list had shown any movement in a period of nine months when analyzed on a quantity basis. On a dollar basis 90% of the value of demand was accounted for by 11% of the items on the active list. Procedures were immediately set up to obtain more up-to-date data with the revised active list which had now been reduced to 144,000 items.

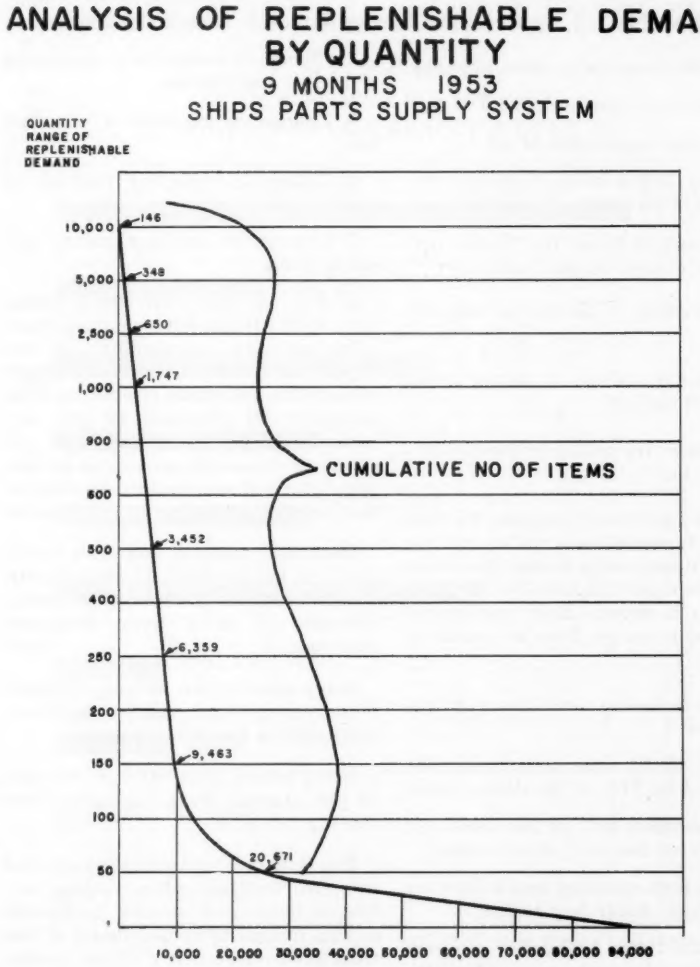


FIGURE NO I

Figure 1 graphically shows the study made for transactions during the first three quarters of fiscal 1953 on a quantity basis.

The salient points immediately evident are:

1. Only 95,000 items showed any movement at all. In other words only

66% of the "active list" showed any activity.

2. 10,000 items had a demand of *one*.

3. 9,000 items had a demand of *two*.

And most significant of all

4. Only 20,671 items showed a demand of 50 or more—5 per month.

Thus only 14.4% of the "active list" could be classed as good sellers.

But quantity of demand is only one factor!

The dollar volume of demand was around 65 million!

What does the dollar demand analysis look like?

Figure 2 graphically depicts the nine months' business on a dollar volume basis. A linear curve masks the details in this field so in figure 2 a bar presentation is shown. Each bar represents a cost range. Bars are suitably labeled.

The outstanding facts shown in this figure are:

1. 11% of the total items demanded accounted for 87% of the dollar value.

2. Conversely 89% of the items cost only 13% of the total dollar outlay.

3. The high quantity best sellers are *not* the high dollar best sellers.

4. In the 1 cent to 5 dollar category 1% of dollar demand occurred but 24% of the item demand occurred.

Consideration of the facts presented by these two analyses showed that the forest was buried more deeply in the trees than anyone believed. How should these facts be utilized? Many avenues of approach appeared attractive including:

1. Change in methods of determination of requirements and procurement.

2. Change in method of presentation of budget justification.

3. Change in methods of distribution.

4. Change in reporting methods of stock status.

5. Change in stocking points and stock levels.

It will be noted that these points have to do with inventory management —the primary responsibility of the Supply Demand Control Point. Which of these lines of attack offered the most promise? All promised to give improved methods of management. All promised to save thousands of dollars. After study it was decided to concentrate on point number 1.

Obviously quantity and price would have to be considered concurrently. Careful analysis permitted the establishment of three basic inventory fractions.

Items showing an average demand of more than 10 per quarter were considered to be fast moving items.

Items having a demand of less than 10 per quarter were classed as slow moving items.

The slow moving items were divided into two fractions. One fraction embraced those slow moving items with a total annual system demand of less than $5.00—the other, all those greater than $5.00.

Symbols were assigned to each basic fraction as follows:

X—low issue rate—very low unit price.

S—low issue rate.

N– high issue rate.

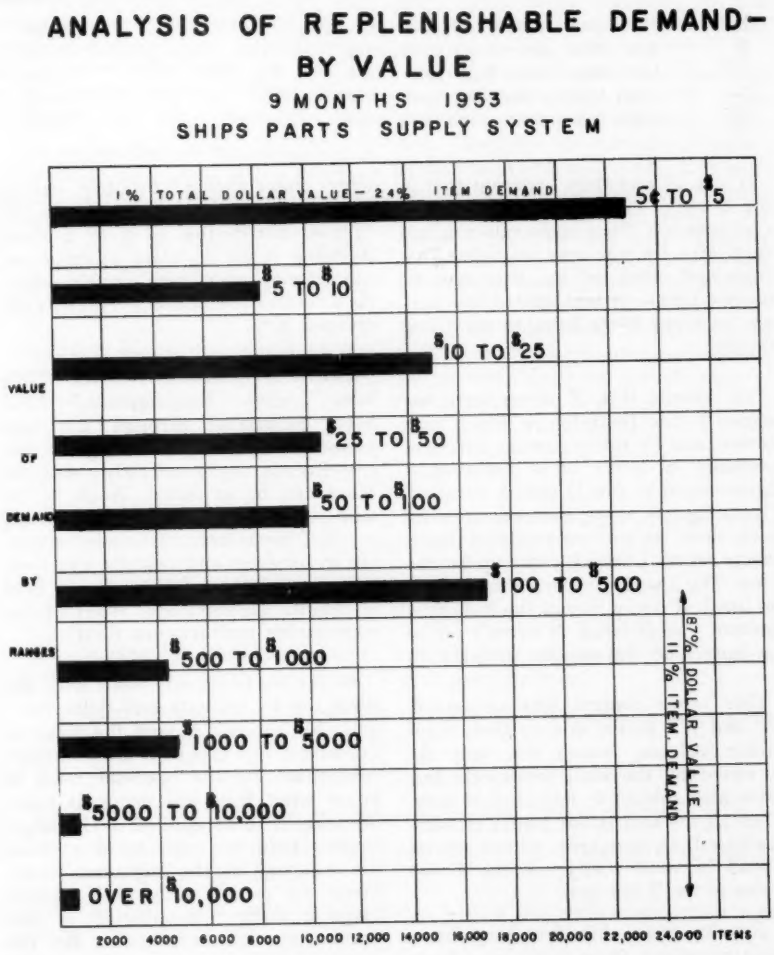


FIGURE NO. 2

When a look was again made at the dollar demand analysis it appeared that the top 15,000 items (dollar wise) would require a very careful procurement reivew—they account for over 90% of the dollar demand. Some of them fell in the S category—some in the N category. With this consideration the fraction table became:

			No. of Items
X	—	low issue rate—very low unit price	24,599
S	—	low issue rate—high unit price	67,618
ST	—	low issue rate—high unit price	11,024
N	—	high issue rate—low unit price	25,762
NT	—	high issue rate—high unit price	6,121

It was immediately apparent that X and S items should not be bought on a set formula. Their issue rate was not only very low—it was sporadic. This explained many of the shortages in specific items—it highlighted the reason for many items being in very long supply.

To remedy this, X items were assigned a low limit figure which was determined by the minimum purchase quantity—S items were assigned a figure equal to the 12 month demand. These figures were entered opposite each item on the consolidated stock status report before it came up for review. The low limits were always to be on hand. If not, a buy of the indicated amount was dictated. N items were to be bought on the regular formula.

One more control was necessary. ST and NT items, due to their high dollar volume, would not only be screened by the stock reviewers but were also subject to technical review. Thus all the best talent would be concentrated on the area where errors would be most costly—on the 17,000 items in the T fraction.

Results from this first step have been excellent. Over buys have been largely eliminated—shortages are very infrequent.

Studies of re-distribution of stocks to meet anticipated demand were initiated. It was very evident that so-called "planned requirements" were causing wholesale re-distribution with only 30% of the planned requirements ever materializing. Another change due to "fractionation" was made. No further distribution of X or S items is being made to meet planned requirements—only firm requirements. As a result distribution action was decreased 30%.

The accomplishments of the "New Look," alias "Fractionation," have been chronicled through the first phase. It can be seen that great improvements have already accrued. More can be expected. Work in the field of reporting, stocking, eliminating many X items from the stock list, etc., are in progress and promise excellent returns. But these are all in the field of Supply Management. What of the engineering maintenance field?

So far we have only dealt with the stock list by velocity and dollar volume. We haven't *named* the trees in the forest. The designer, the maintenance man and the operator need to know what they are using. If fractionation is to be applied to the engineering field we must know at least the category of the high use items. Since the initial study of 9 months usage a further compilation of two years usage has been made. For the purpose of this article the first 10,000 items of this new listing have been selected for study. For the time being cost is not considered.

It was apparent when the nomenclature of the 10,000 items under study was considered that most items would fall into about 28 distinct categories. Besides these 28 a very large field was

covered but these varied to the extent that they could very well be excluded. Among this miscellaneous group were such things as: covers, strips, tubing, ferrules, chain, shims, dessicant, hose, cable, lenses, etc., etc.

Having decided on the categories a compilation was made of the number of different items (stock numbers) in each category. After compiling this list into order by decreasing number of different items, for certain significant categories, total quantities of these items were tabulated.

Figure 3 shows the results of the two tabulations. The numbers in parenthesis alongside or under the category name is the quantity of that category issued in a two-year period.

It must be remembered that the items under study are only those stocked in the Ships Parts Supply System. They do not include Aviation, Ordnance, Yards and Docks, Electronics or special Submarine material. They do not include the many thousands of items carried in the General Stores Supply System. Furthermore they do not include the many items of ships parts which are fabricated locally. Above all it must be remembered that these are "parts peculiar"—peculiar to the design or manufacture of one supplier.

With these thoughts in mind what do we find?

2083 different and distinct types or sizes of gaskets were issued in the two-year period out of the top 10,000 items!

20.8% of the best sellers are gaskets.

Quantity wise 5,371,760 gaskets were consumed in 24 months.

This means that 7,360 gaskets were replaced every single *day* for two years in components supported by the SPCC on a *peculiar* basis.

Napoleon's Army may have moved on its stomach but it appears the modern U. S. Navy is floating in a sea of gaskets!

1083 different items of *peculiar* screws, studs and bolts.

1,790,407 of this category were consumed in a two year period.

This, despite the thousands of *standard* screws, studs and bolts carried in the General Stores System.

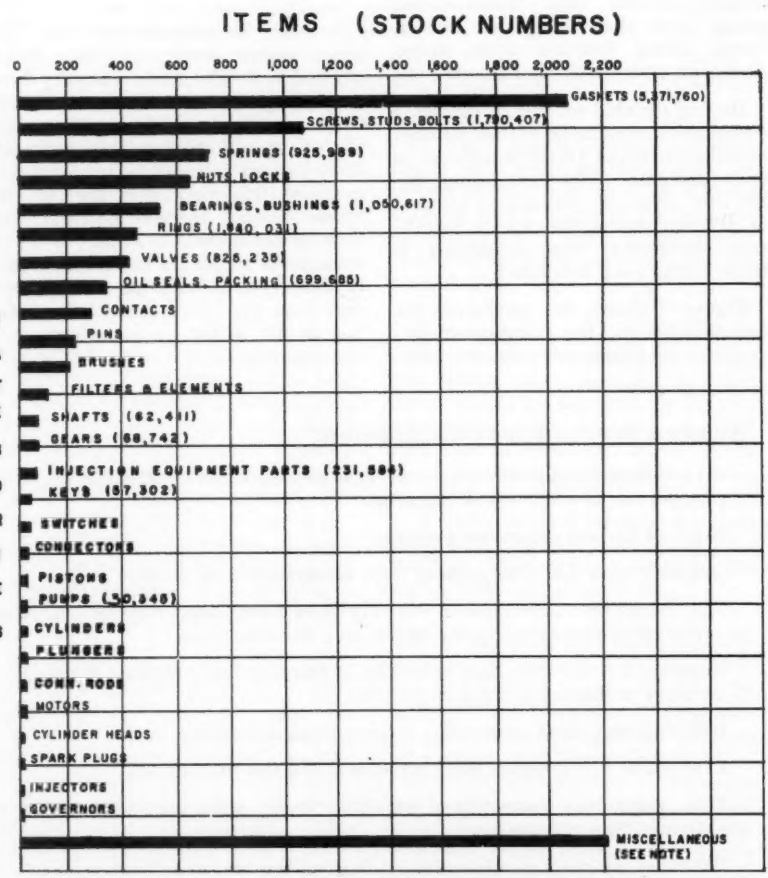
720 different stock numbers for springs with a two year issue quantity of almost a million.

454 varieties of rings, mostly piston rings, for a grand total quantity of 1,840,031.

428 separate types and sizes of valves (in the top 10,000) with a quantity of 825,235.

Gears appear near the top of the best seller list. 81 different types with an issue figure of 68,742.

Keys!—usually a rectangular piece of metal—to the tune of 48 types and 57,302 quantity wise.



NOTE- INCLUDES COVERS, STRIPS, TUBING, FERRULES, CHAIN, SHIMS, DESSICANT, GUIDES, HOSE, LENSES, HAND-WHEELS, CABLE, LEVERS, CARBURETORS, IMPELLERS, ETC., ETC.,

NUMBER ITEMS EACH CATEGORY ISSUED

SHIPS PARTS SUPPLY SYSTEM

TWO YEARS USAGE

(NUMBERS IN PARENTHESIS SHOW QUANTITY) (TOP 10,000 ITEMS ONLY)

FIGURE NO. 3

These are some of the high lights that appear from a cursory study of figure 3. Before attempting to point out what can be done to improve this situation it appears to be in order to enumerate some of the reasons why such conditions exist.

First let's consider why the wide variety of items exists in each category.

The Ships Parts Supply System supports some 101,000 different components. All but a fraction of 1% of these components are of the design and manufacture of industry. Not more than a handful of components have been designed in detail by the Navy or other Governmental Agencies. In many cases the component was designed to meet a Navy performance specification. In many other cases a manufacturer's commercial product was accepted in toto. In other cases an adaptation of a standard product was made.

Any designer of technical components is always torn between three divergent viewpoints. As an engineer he wants to have the best performance possible. He must, however, consider the production man and design to fit the company's methods and facilities. Last but not least his design must be as cheap as possible to meet competition. He is influenced by other factors of course including:

Ease of maintenance.

Availability of materials.

Patent rights.

Desire to keep company's product peculiar.

As a result of considering all of these factors any design becomes a compromise. If proven units are in existence they will be incorporated where possible. If a one-cent paper gasket will suffice it will be used—save cost. If the company does its own heat treating of stressed parts, special studs, springs, nuts, rods, etc., will be incorporated instead of more standard parts. In short everything is working to encourage the designer to refrain from incorporating standard parts in his component. Furthermore he is probably not aware of the existence of Federal Catalogues and almost certainly has never heard of the Navy's General Stores Catalogue.

When we get into the more complex components and systems another factor mitigating against any standardization arises—research engineers test and design sub-components. When these are incorporated into the whole we find in many cases completely different hardware, fits, materials and standards of workmanship.

Before World War II a diesel engine was designed, built and developed in the Research Laboratory of a large company. When the Navy ordered this engine in quantity it was turned over to a manufacturing division of the company. To the production man's horror he found over 58 sizes, types and shapes of the simplest screws, nuts, bolts and common hardware. Production was delayed for months while these simple parts of the engine were redesigned. Even so the Navy is supporting many strange new hardware devices on this particular engine.

An example of another nature can be found in the connecting rod bolts of a gasoline engine which is used rather widely in the Navy. The bolt is of a diameter, length and screw thread size such that it could be drawn from General Stores. There is only one drawback. The connecting rods travel

so close to the ribs of the crankcase that part of the hex head of the bolt was milled off at an angle to obtain safe clearance. This immediately became a *peculiar* part and joined the family of 1083 different screws, studs and bolts.

The causes cited for the wide variety of sizes and types in each category only give some of the basic reasons. There are many others—we do not need to belabor the point. Certainly something should be done where 28 categories of the 10,000 top best sellers comprise 7,784 stock numbers.

Having considered some of the reasons why the Ships Parts Supply System has acquired such a wide *variety* of material, let's take a look at the reasons for the use of such huge quantities.

Prior to 1940 shipboard installations were relatively simple as compared to today. Installation of new components had been gradual with sufficient on board repair parts furnished at time of installation. Above all maintenance practices were at a high level due to the long term, experienced personnel then available. Every effort was made to *repair* worn or broken parts instead of resorting to *replacement*.

After 1940 components became more complex. With the advent of radar, the use of high speed diesels, higher temperature and pressure steam, new fire control gear, complicated electric machinery, etc., maintenance problems increased by leaps and bounds. Space was at a premium and accessibility had to be sacrificed. Hand-in-hand occurred an overwhelming dilution of the trained maintenance people then available. As might be expected the emphasis shifted from "repairing it" to "replacing it."

During the war but little time was available for preventative maintenance so that the life of many parts was consequently shortened. As a corollary the "insurance" philosophy appeared. This practice consisted of replacing everything possible if the repair parts could be obtained in an endeavor to keep everything new. During the short life of the "Salvage Collection Center" this was daily manifested by the many boxes of bearing received with the original tool marks still visible.

This "replacement" and "insurance" concept became so ingrained during the war period that it still carries on today.

One other large factor promoting wholesale use of repair parts is the ease of obtaining material today. (Remember we are speaking of "best sellers.") It is APA material and to the consumer is apparently "for free." There is no over obligation of allotment involved and therefore no check rein.

In an endeavor to reconcile overhaul costs for two sister-ships at different Shipyards the writer went to the "Departure Reports." It was found that the "high cost" Shipyard was definitely high in direct labor charges. But when the APA figures were examined the reason was immediately apparent. The "low cost" Yard showed inordinately high APA charges. When APA was added to direct labor the two Shipyards had expended nearly the same amount *on the face of it*. What didn't appear was the cost of procuring, distributing, stocking and accounting for the APA material. This is one example of the "replace" versus "repair" philosophy.

Several other factors work to cause wholesale replacements. Probably one of the worst was the practice that existed for ship's parts in allowing the

manufacturer to recommend on-board and stock repair parts. Usually the manufacturer has no concept of what the Navy is capable of in the way of maintenance. He accordingly recommends a list of parts which he would require in his own shop to completely restore a piece of equipment. As a result the stock list has become burdened with items available in general stores, with items easily fabricated aboard ship or at a shipyard and with items that easily lend themselves to repair. Once it is on the stock list it becomes available. Once it becomes available it is used for replacement and the old one thrown away. This is now being corrected by the new Provisioning procedures which allow the Supply Demand Control Point to review the manufacturer's recommendations. It does not however eliminate those items already on the stock list.

This leads into the subject of fabrication. For some years the Ships Parts Control Center has intensified its efforts to designate certain parts for local fabrication. A complete study of availability of material in general stores, the ability of local personnel and the availability of tools is made. In spite of these efforts in many cases the change to "fabricate locally" is resisted. Again the "replace" philosophy predominates.

Gasket philosophy apparently dictates that the cheapest gasket possible be installed. This permits the gasket to be thrown away each time the connection is broken. The designer forgets the huge quantities that must be procured, distributed, stored, inventoried and accounted for. He forgets that each ship must have all gaskets on hand before it dares to inspect or overhaul its equipment.

The writer very vividly remembers his experience in this regard when commanding a submarine in Philippine waters prior to World War II. Three main engines had been completely ovehauled. The fourth was badly in need of an overhaul. No such overhaul was possible however as no gaskets of about ten sizes were on hand. That submarine was hampered for months due to a shortage of gaskets—gaskets which could not be reused. When the overhaul was accomplished many bearings, rings, etc., were renewed which would not have been necessary if the engine had been overhauled on schedule.

In other words the cheapness of the original gasket that must be thrown away has decreased reliability and added untold hidden costs.

Many of the other categories in figure 3 can be shown to owe their huge volume to the original designer. The designer who designed for performance and cheapness. The designer who was not given all the basic tools he needed. The designer who lost sight of the maintenance problem.

Last but not least is the question of adequacy of maintenance practices procedures. Manufacturers instruction books are in general very good. Maintenance procedures outlined in these books however are sometimes of questionable value. They are necessarily based on results obtained on the test floor. Where experience has been gained in commercial application these are not always valid for components installed in naval vessels. The Bureau of Ships Manual is an excellent general guide but obviously cannot cover the details of maintenance practices for individual components.

Inspection of maintenance practices aboard individual ships for identical

components reveals a wide variety of procedures. Most of them are influenced by the personalities and experience of the supervisory personnel. Some are good—some are bad. In some cases no procedure exists. As a result many more repair parts are used than necessary—either through the "insurance" philosophy or the "run it until it breaks down" point of view.

Having diagnosed the disease it behooves the doctor to suggest a cure. Being an unexplored disease most certainly no cure-all is going to be immediately forthcoming. Certain lines of attack however can be pursued and at least a palliative prescribed.

Let's first look at the variety of items in each category. For the time being it seems best to confine ourselves to the field of new components as far as variety of parts is concerned. This aspect can be faced at the time of letting new contracts. It can be implemented to produce greater standardization at the time of Provisioning.

From figure 3 it has been seen that the widest variety is found in the gasket, screws-studs-bolts, springs, nuts, bearing, rings, valves and gears categories. When negotiations are started, the contractor should be informed that the final contract will contain a clause specifying the greatest possible standardization of parts within the component or system itself. As an example, gaskets of the same size should be of identical material—material required by the most severe use any one gasket will be called upon to face. Screws, studs, nuts, springs should be made identical when possible using as standard the one expected to be subjected to the most severe use. Oil seals and packing, even though of different size, should be specified of like material—material that can be stocked in bulk and fitted. Instead of bronze gears, fiber gears, steel gears—herring bone gears, spiral gears, spur gears—settle on the minimum types possible even though some are far over-engineered for the purpose required.

Consider the valve problem. Particularly in systems, as opposed to individual components, it has become the practice to merely specify size and possibly general type. A 2″ valve specified by a designer in a system may mean parts for five different makes being incorporated in the Navy Supply System. This has happened. When the shipbuilder or component prime contractor buys his valves he buys on a competitive basis. Any number of 2″ valves will do the job—but the insides are different. The system plan should specify identical valves. Remember we have only looked at the variety of valves which show high issue rates. In this field there are 428 different valves. In the whole stock list there are several thousand; so many in fact that the SPCC has been forced to issue a special valve catalogue. A catalogue for *valves peculiar*. Here then is a potent field for standardization.

After a contract is awarded the new procedures call for a "Provisioning" conference. It is the intention of the SPCC and other Supply Demand Control Points to conduct pre-provisioning conferences before a design is finalized. Here is the golden opportunity to get in a goodly lick for standardization. Navy personnel should come to the conference armed with

General Stores Catalogues

Supply Demand Control Point Catalogues

Stock Lists

Federal Stock Catalogues

and a burning determination to pre-

vent a multiplicity of common hardware items being superimposed on an already overburdened stock list. When the manufacturer knows what is wanted, and has the tools to provide what is wanted, experience has shown that he will generally be cooperative.

The above reasoning applies equally as well to the shipbuilder. In his design of systems, of enclosures, of deck gear and other ship-builder furnished items a knowledge of what is now available can reduce the influx of new items tremendously.

What can be done with presently installed components and systems? Manifestly no sweeping re-designs are possible. The ever present ship-alt program however gives us one weapon to use. When ship-alt plans are being prepared, a designer, with his eyes open on the General Stores Catalogue and the Supply Demand Control Point's Stock List, can find many places to substitute standard material for *peculiar*. In addition he can make sure that the new items conform in many cases to those in existence.

Consider now the quantities of items. The complexity and lack of accessibility of equipment we must live with. The "replacement" and "insurance" concept can only be changed by education and experience. The Bureaus, Fleet Commands and Shipyards are in many cases performing noble efforts in educating personnel along proper maintenance lines. It is not believed enough is being done in this respect however due to a lack of information at the Bureau and Fleet level as well as a lack of man-power to analyze the information available. Some months ago an attempt to utilize the "trouble" reports from ships which are forwarded to BuShips was made. It was found that these were sketchy and in such small volume that they afforded little information. It is suggested that the following steps be taken in this regard:

(1) An intensified effort to insure the receipt of all "trouble" reports.

(2) An assurance to the fleet that such reports are not a reflection on the ship itself.

(3) An adequate and systematic analysis of these reports.

(4) An authoritative bulletin of maintenance practices derived from such an analysis.

As far as our next factor regarding ease of obtaining APA material is concerned, the answer seems clear. Have the consumer pay for it through an authorized allotment procedure exactly as he pays for NSA material. It may be only a paper transaction at the Bureau or Supply Demand Control Point level but it will promote cost consciousness. Cost consciousness will promote better maintenance practices. The approach suggested by Commander J. A. Hack, USN, in his article "Captain O'Shauguessy — Business Man In Blue" in the February 1953 JOURNAL of the A.S.N.E. is very pertinent to this subject.

The problem of the manufacturer recommending any and all parts is now on its way to solution as previously indicated. The Supply Demand Control Points however must drastically cull their present stock lists of all the extraneous material now present. Many of these items do not meet the criteria for stocking in General Stores under the NSA. It is General Stores type material but cannot be financed by NSA. Cannot the General Stores Supply Office be granted an APA allotment for this purpose?

Now we are back to the big volume business due to the design. The designers lack of knowledge of what is available and his desire to produce an item as cheaply as possible is a primary cause of our huge issues. Initial cost should not be considered alone. What is continuous cost of maintenance? What is effect on reliability and availability? Let's look at some specific examples to illustrate the point.

Right near the top of our best seller list is a grommet (so-called)—really a gasket. It is a neoprene molded ring about 2½" O.D. It is installed in the cylinder head of one of the most widely installed diesel engines in the Navy. Over 25,000 are used each year. The initial cost is 10 cents. It has water on one side and lubricating oil on the other. *It is thrown away nearly every time the cylinder head assembly is disassembled.* Why? It has crumbled, or torn or is stuck or "we had better put a new one in any way." *Possible* solution—replace with a ring of "teflon"—cost about four times as much —life about eight times as great! The cost though is really immaterial. If a "teflon" gasket were only replaced every fourth time the head was disassembled the savings would still be tremendous. Only 6250 would be used a year instead of 25,000. Think of the money saved in procurement, stocking, distribution, inventorying, etc. But above all think of the more ready availability of material and the increased reliability.

Take another gasket. Material—asbestos. Use—small boat diesel—type most widely used in Navy. In contact with fresh water. 48,000 used in *one year.* Cost 3 cents. Thrown away every time outlet manifold connection is broken. Replacement by any one of many more durable materials at a cost of five times as much would pay incalculable dividends in continuous cost saving and maintenance practices.

Well up on the list we find a common brass rivet. It is used to secure the brake lining for a winch—cost 5 cents. But 5,000 of these rivets are used each year—a *peculiar* rivet not in General Stores. Here is the type of item for which a redesign appears in order or a shift to more commonly available rivets.

Consider another gasket made of plant fibre—another name for good wrapping paper. Usage is 15,000 per year. Used in a large diesel engine in contact with fresh water at a maximum temperature of 180°. Again a type that is thrown away each time connection is broken. More expensive "teflon," neoprene, or other material should reduce the usage to 3000 or less per year with all the consequent advantages.

Looking into springs and their end use reveals some surprising items. Springs vary from a piece of thin mild steel through music wire up to heavily loaded coil and spiral springs. Examples are numerous where the high issue rate is due to a low cost item. One spring has an issue rate of 8000 per year. Relatively few engines utilizing this spring are installed in naval vessels. It is made of music wire to load a packing gland. It costs 5 cents. Here a redesign is definitely in order. 1000 per year would appear to be a fair usage rate for this item and could be achieved with many types of material at only slightly increased cost.

The above are only a few examples indicating a method to cut down the tremendous usage of the more common *peculiar* materials. A systematic survey and engineering study is required to reap the real dividends available in this area. Such a study would go into valves, gears, bearings, oil seals, injection equipment and other categories on the basis that high issue rates are causes for investigation; an investiga-

tion to produce items that will give maximum wear regardless of initial cost if the continuing cost and reliability are improved.

The last subject covered in our diagnosis was that of the adequacy of maintenance practices and procedures. Various technical sections of the Bureau of Ships have issued excellent directives regarding preventative maintenance. Some have acquired new indicating and test equipment to be used aboard ship. Some have revised operating instructions to permit greater reliability of operations. Most of these efforts however have been sporadic due to the very heavy workloads of the sections involved. A more centralized approach is believed advisable. Here the "trouble" reports section would appear to be a possible solution.

Certain specific advances by industry can be cited which might aid the Navy in its maintenance problems. In the last few years the Bureau has procured oil testing kits for shipboard use. These kits measure sediment, dilution, acidity and other properties of lubricating oil. They tell when to change oil and thereby do increase reliability and improve maintenance. Industry however has gone one step further.

One of the large diesel engine locomotive builders began, about four years ago, to make spectrographic analysis of used lubricating oils. Laboratory results, using an electron microscope, were so encouraging that the cooperation of many of the company's railroad customers was solicited. Some forty-one railroads have taken part in the program. Some of the results are really spectacular.

In this type of analysis lubricating oil samples are taken on a set time schedule from each diesel engine. These samples are forwarded to properly equipped laboratories for analysis. Some railroads have procured their own equipment; others use commercial facilities. The sample of oil is reduced to ash and then analyzed with the electron microscope for metallic elements present. These elements include silver, aluminum, chromium, copper, iron, magnesium, lead, silicon and tin. Careful records for each engine are maintained. These records are closely watched for an increase in any of the entrained elements. When a large increase is noted the maintenance force is notified of the possibility of engine failure and an examination recommended. As an example, a large increase in chromium would indicate possible failure of chrome plated cylinders liners.

From past experience and standards that have now been set-up the laboratories have had a surprisingly high batting average in predicting trouble.

One railroad reports that in one year's time this method of analytical control prevented incipient failures of 52 diesel locomotives. It is estimated that the potential engine damage would have cost the railroad between $500,000 and $1,000,000. Many railroads report that use of this system has permitted a general extension of time between overhauls.

It appears that this procedure offers considerable promise for naval use. It would be particularly useful at shore bases for landing craft and small diesel driven boats.

This is only one of many new maintenance practices now being investigated. In the field of filtration, air cleaning and new preservatives industry is making rapid strides. An evaluation of some of these new prac-

tices with a view to adaption for naval use appears well worth the effort.

To summarize our look at the data developed by one Inventory Manager the following facts seem pertinent:

1. There exists a far too large variety of items in each category of material in the Ships Parts Supply System and by inference in the entire Supply System.

2. There are far too many common hardware items carried as "parts peculiar."

3. There is an inordinately high issue rate in these common hardware items.

4. These high issues appear to indicate a general attitude of "replacement" as opposed to "repair."

The reasons why the above exist have been explored and some remedial steps suggested. It is known that various activities are constantly working to improve reliability of material and to provide better maintenance practices. It appears however from the look that has been taken herein that the following steps will add considerable impetus to present efforts:

1. Educate potential contractors as to the need for standardization of materials within components wherever possible.

2. Make available to potential contractors all possible catalogues, lists and other data that will permit them to utilize material identical with that already in use by the Navy.

3. Wage continual war against the use of "peculiar" material when standard material will suffice.

4. Have shipyards endeavor to standardize when performing ship-alts.

5. Maintain a constant program of education to the fleet and repair activities on improved repair and maintenance practices.

6. Revitalize the use of "trouble" reports with a central group assigned to analyze them and advise repair activities of information gleaned from such analysis.

7. Have this or some other group spearhead an attack on the stock lists along the lines suggested in this article.

8. Keep constantly abreast of industrial experience in new maintenance procedures for possible Navy use.

Happily the Bureau of Ships has recently established a "Value Analysis" program. A small but very competent group has begun operation. The writer feels that this program will prove to be one of the most productive efforts ever initiated in the fleet support field. May he suggest that some of the proposals offered here be used as a starting point for this new program. The Inventory Managers have a wealth of data as a starting base. There is money to be saved—reliability to be improved—efficiency to be gained—A Fleet to receive better support.

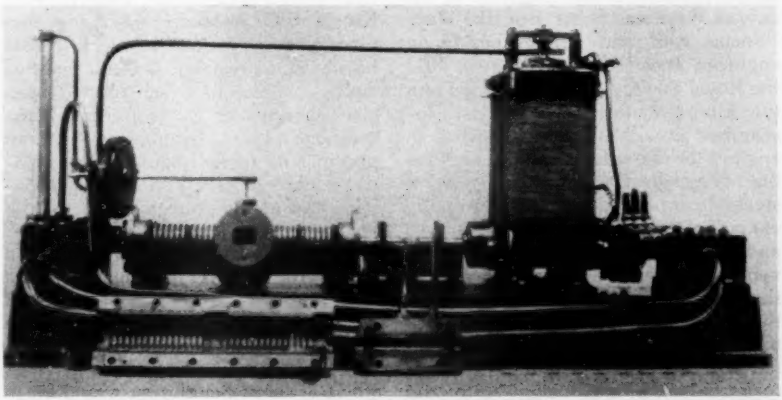
THE HON. SIR CHARLES A. PARSONS

A CENTENARY TRIBUTE

ACKNOWLEDGEMENT

This tribute to Sir Charles Parsons was written by Engineer-Captain Edgar C. Smith, O.B.E., R.N. (Retired) and was printed in the 11 June 1954 issue of "Engineering."

In his Hunterian Oration to the Royal College of Surgeons delivered on February 15, 1932, to mark the 204th anniversary of the birth of John Hunter, the late Professor Wilfred Trotter discussed the significance of the commemoration of great men, asking "what do we wish and what do we attain in the many activities by which in general we pursue, or suppose ourselves to pursue, in such commemorations." The commemoration of heroes, he said, was one of the most widespread of human impulses and primitive man by devious ways sought to assimilate the heroic virtues of the dead. Even the commemoration feasts of to-day have their origins in prehistoric times. "The conscious and ostensible motives," he added, "under



Parsons' original steam turbo-generator of 1834, now preserved in the Science Museum.

whose influence we approach the commemoration of great men are, first, to contemplate in humble piety and emulation a largeness of mind and character that far exceeds our own, and secondly, to seek inspiration from struggles heroically engaged and perhaps triumphantly won." The subject has engaged other thinkers; one wrote "We commemorate to instruct ourselves, to inspire others to act in a way similar to that of the men we revere, perhaps most of all to impress the fact of the debt of the living to the past."

The commemoration of notable men and events has become a feature of our age, stimulated no doubt by the spread of education, the ease of communication, the increase in the number of societies and a greater appreciation of the value of history. It is but fitting that a technical journal which during more than 60 years has recorded the progress of the steam turbine (and, through the writings of a former member of its editorial staff, the late H. M. Martin, contributed something to its technical development), should recall the centenary of Sir Charles Parsons, recognized all over the world as the greatest power engineer of his day, as Watt was of his. But like Watt, Parsons was many things beside an engineer. It is true that when in 1911 the Royal Society of Arts awarded him the Albert Medal it was for his "Researches into the action of steam in engines of the turbine type, and for his invention of the reaction type of steam turbine and its practical application to the generation of electricity and other purposes," but Parsons' inventions covered a wide field and at the unveiling of the memorial window to him in Westminster Abbey in October, 1950, Sir Frank Smith said that to him "Parsons's outstanding characteristics were his insight into the mechanisms of nature, his wonderful engineering knowledge, his great experimental ability and his amazing courage in face of technical difficulties. He never admitted defeat."

Quite apart from the record of his achievements, the story of Parsons, and of his brother Richard Clere Parsons (1851-1923), is of unusual interest for they were the first members of any ancient, wealthy and noble family to combine a severe training in mathematical science with practical experience in engineering workshops, and to become engineers by profession. Many men of high degree, such as Boyle, Cavendish, Lord Crawford and the Rayleighs, have devoted themselves to scientific pursuits, and the names of others, like the Marquis of Worcester, the Earl of Stanhope, Lord Dundonald and the Duke of Bridgewater are to be found in the histories of engineering, but the career of Parsons was entirely different from theirs.

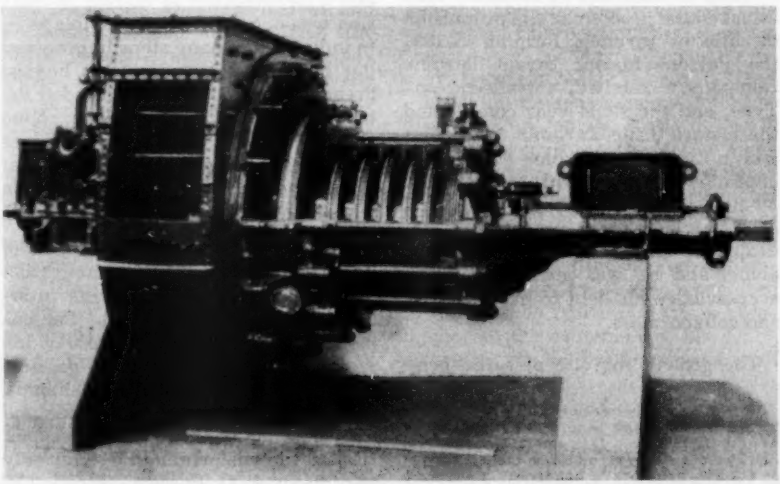
As the official records show, Parsons was born on June 13, 1854, at 13 Connaught-place, Hyde Park, London, being the sixth and youngest son of William Parsons, 3rd Earl of Rosse (1800-67), who by the construction of the great reflecting telescope at the family seat, Birr Castle, Parsonstown, King's Co., Ireland, had made that place a Mecca for astronomers. In 1854 he was still President of the Royal Society, an office to which he had been elected in 1848. "Estimable in all the relations of life, he pursued without pretensions or self-seeking the combined careers of a philosopher, a patriot and a philanthropist."

Of the Earl's six sons, the second and third, William and John, died in 1855 and 1857, both aged eleven. Of the others, Laurence, who became the fourth Earl, was born in 1840 and died in 1908, while Randal, who for 41 years was Rector of Sandhurst, was born in 1848 and died in 1936. For none of them were there any of the early

struggles of Watt or Faraday or Edison. Their studies were directed by men of high attainments; the observatory workshop was always open to them and country sports alternated with yachting and travel. In accordance with tradition they all studied at Trinity College, Dublin, Clere spending the years 1869 to 1873 there before entering upon his apprenticeship with Easton and Anderson of Erith, Kent.

Charles spent but two years at Trinity College from which he passed to St. John's College, Cambridge, which he left in 1877 after a distinguished career. From Cambridge Charles went north and it was on Tyneside that all his epoch-making work was done. About four years were spent in the engineering shops of Armstrong at Elswick, famous for its ordnance and hydraulic machinery, and about two years with Kitson and Company, of Leeds, of which Clere was a partner from 1880 to 1887. It was during these years that Parsons invented his epicycloidal steam engine, a number of which were made at Leeds and Erith. At Kitson's he was much engaged with the application of rockets to the propulsion of torpedoes, but the high-speed engine was never far from his thoughts. By 1883 he had probably spent more on experiments than he had earned, but leaving Kitson's he joined Clarke, Chapman and Company, at Gateshead, putting £20,000 into the firm. By April, 1884, he was able to take out his patents for "Improvements in electric generators and in working them by fluid pressure" and "Improvements in rotary motors actuated by elastic fluid pressure, and applicable also as pumps," patents comparable in importance with that of Watt of 1769.

Fortunate in so many ways, Parsons was also fortunate in point of time, the world being ready for what he had to give it. Versed in the theories of Carnot, Joule, Clausins and Rankine, familiar with the dynamos of Gramme, Brush, Siemens and Edison, realizing the limitations of the reciprocating steam engine, and a witness of the birth of the incandescent lamp



The radial-flow turbine which was fitted to the historic "Turbinia."

and the central power station, he visualized in its entirety the problem of power supply. At Gateshead a considerable number of his small high-speed non - condensing turbo - generators were constructed mainly for use in ships, and some of these to-day are treasured possessions of museums, the original 7½-kW machine, illustrated opposite, being preserved in the Science Museum, South Kensington.*

At Gateshead he was the head of the electrical department, but he was never cut out for a junior partner. So in 1889, taking his fortune in his hands, he left Gateshead with his capital, but without control of his patents, and crossing the river, on a plot of two acres at Heaton near Newcastle-upon-Tyne, founded the now world-famous firm of C. A. Parsons and Company, Limited. Debarred for the time from developing parallel-flow turbines he designed and constructed radial-flow turbines and condensing turbines. The first of the latter type is now preserved at Heaton. Soon after this, through arbitration, he regained control of his original patents and at the same time attacked the problem of the propulsion of ships by turbines, forming in 1894 the Parsons Marine Steam Turbine Company, Limited, Wallsend-on-Tyne, and the same year constructed the historic little *Turbinia*, fitted first with a radial-flow turbine (illustrated opposite) and then with three parallel-flow turbines driving three shafts each carrying three propellers. Naturally, he did not fight all his battles alone, and he was always ready to acknowledge his debt to his assistants and collaborators.

The growth the size of turbo-generators, the building of great power stations and the development of the marine steam turbine are thricetold tales to be found in innumerable papers, journals and books. The sensational debut of the *Turbinia* at the Diamond Jubilee Review at Spithead in 1897 was followed by her visit to the Seine at the time of the Paris Exhibition of 1900, and it was during this visit that the Havre naval constructor Augustin Normand, remarked of Parsons, "Ill ne pense qu' a la turbine; il y pense sans cesse." The next few years saw the launching of the Clyde steamer *King Edward*, the triumphs and tragedies of the destroyers *Viper* and *Cobra*, the building of turbine-driven cross-channel steamers, and the crossing of the Atlantic in 1903 by the turbine yacht *Emerald*. Then came the cruisers *Amethyst*, the Allan liners *Virginian* and *Victorian*, the battleship *Dreadnought*, and the Cunard vessels *Mauretania* and *Lusitania*. These and their immediate successors were all direct driven, but in 1909 the cargo ship *Vespasian* was fitted with turbines and helical reduction gearing and a new chapter in marine propulsion was opened. It is impossible even to indicate the many steps in progress, but Parsons saw some of his highest dreams realized when he attended the trials of the Clyde steamer *King George V* fitted with geared turbines of 3,500 h.p., supplied with steam at 550 lb. per square inch generated in Yarrow boilers.

So the years passed, the turbines of de Laval, Curtis, Zoelly, Ljungström and others contributing to the problem of power production. Parsons meanwhile engaging in a host of investigations relating to steam, gearing, propellers, searchlights, diamonds, musical instruments, optical glass and the construction of great telescopes. He had the misfortune to lose his only son, Major A. G. Parsons, in action in 1918, but he had the pleasure of see-

*A letter to the Editor from Mr. Gerald Stoney published on page 193 of the issue of August 12, 1932 (vol. 134), maintained that the first Parsons steam turbine was built for 6 h.p. or 4½ kW, not 7½ kW, but Messrs. C. A. Parsons and Company have recently confirmed that it was 7½ kW.

ing his only daughter, Rachel, pass through the engineering course at Cambridge and enter the Heaton works. Lady Parsons, whom he married in 1883, and who died on October 16, 1933, was to him what Madame Pasteur was to Pasteur, and in the realm of technical literature there is probably no finer tribute to a woman than Mrs. Houston's appreciation of Lady Parsons, published in the *Transactions* of the North East Coast Institution of Engineers and Shipbuilders, of which she was an Honorary Fellow. It was Lady Parsons who helped to found the Women's Engineering Society, who turned Ray estate, near Kirkwhelpington, into a place of beauty—now alas, derelict—and erected the memorial to Parsons in Kirkwhelpington Church, the errors on which are difficult to explain.

Honors in abundance came to Parsons: the C.B. in 1904, the K.C.B. in 1911 and the Order of Merit in 1927. There were doctorates, honorary memberships and presidencies. In turn he received the Rumford, Grahof, Albert, Franklin, Faraday, Kelvin and Bessemer Medals, and in 1928 the Royal Society awarded him its Copley Medal, the most famous prize in the world of science. As the son of a past-president of the Society, he evidently felt great satisfaction in being so honored, and to a letter of congratulation from his old Newcastle friend, Professor Phillip Bedson, replied, "Certainly it seems that the Scientific and Industrial Research Department, and the Institution of Engineering and Technical Schools at many universities, colleges, etc., during the last 40 to 50 years is having the effect of bringing science into closer touch with the arts. The last engineer of any professional note to receive the Copley Medal was Smeaton 169 years ago; it was the year that he rebuilt the Edistone (*sic*) lighthouse, but this was a far less important work than many other civil and mechanical works carried out by him subsequently."

In 1928 Parsons had but three years left to him, but they were years of activity and included a visit to South Africa with the British Association. Needing a holiday, early in 1931 with Lady Parsons he left England in the S.S. *Duchess of Richmond* for a cruise to the West Indies. The travelling and expeditions, however, proved too much and as the sun set over Kingston Harbor, Jamaica, on February 11, 1931, he passed away. His body was brought to England and, on March 3, the day of his funeral among the Northumbrian Moors, a memorial service was held in Westminster Abbey, attended by a great gathering of men of all ranks. Soon afterwards a Parsons Memorial Fund was inaugurated and on October 5, 1950, a window to his memory was placed in the North Aisle of the nave of the Abbey. The figures in the window are those of Henry III and Abbott Richard Ware, but the window includes the arms of Parsons and the inscription "to the memory of Charles Algernon Parsons, O.M., K.C.B., F.R.S., Marine Engineer; born A.D. 1854, died A.D. 1931."

Near the Parsons window is that to his great forerunner, Richard Trevithick, who gave the world the high-pressure steam engine and the locomotive, but who died in poverty and was buried in an unknown grave at Dartford, Kent. Appreciated by few in his lifetime, Trevithick's contributions to engineering are fully recognized to-day and on April 23, 1935, to commemorate the centenary of his death, a service was held in Dartford Parish Church, at which an address was given by the late L. St.L. Pendred. "Savery, Newcomen, Watt, Trevithick, Symington, Stephenson, Parsons," said Pendred, "What a constellation of genius. Can any nation of the whole

earth show its like? And in the midst three bright particular stars shining, like the Baldric of Orion, greatest among the great. Newcomen, the originator of the steam engine; Trevithick, the first revolutionary bringing us the high-pressure engine; Parsons, the second revolutionary, getting rid of the piston, changing the engine radically, giving the world the steam turbine. Names, these, to be written for ever in gold."

NOISE IN REDUCTION GEARS

ROBERT TAGGART

THE AUTHOR

recently was in charge of the Noise Section, Applied Science Division, of the Bureau of Ships. He received his Bachelor of Science degree in Naval Architecture and Marine Engineering from Webb Institute of Naval Architecture in 1942. He served with the Consolidated Steel Corporation, U. S. Maritime Commission, and U. S. Army Transportation Corps prior to his employment in the Navy Department. His Navy Department position included the administration of research investigations in the fields of airborne and underwater noise reduction of naval vessels. It was while he was in that position that this article was written. At the present time he is Chief, Analytical Engineering Department, Reed Research, Inc.

I INTRODUCTION

Since Sir Charles Parsons installed the first marine reduction gear in the *Vespasian* in 1910, the problem of gear noise has been a source of extreme concern to the operating marine engineer. As powers and speeds have increased and as stronger and lighter materials have been incorporated, the search for means to quiet gears has been continually intensified.

Until World War II, the prime concern was the reduction of airborne noise which caused acute personnel discomfort. Gears were replaced for this reason and corrective measures were applied. These corrective measures included gear case damping and the insertion of damping rings in the gear wheel rims. Many ideas were formulated regarding the causes of the generation of noise in gears, and design measures to control this noise generation were sought.

With the increased technical development and employment of listening sonar in World War II as a means of detecting submarines, grave concern was expressed over the excessive waterborne noise caused by submarine propulsion gearing. Many empirical methods of airborne noise reduction treatment were applied to these gears with little or no success. It finally became generally accepted that the transmission path of the noise was through the bearings, feet, and foundation structure of the gears. The installation of isolating pads under the gear feet was attempted with singular lack of success. This led finally to the removal of reduction gears from submarines and the substitution of large,

low speed, direct-drive motors. The fact that the Navy tolerated the increased weight and space requirements of these motors, even to the point of installing a blister in the pressure hull, strongly emphasizes the vital need for a quiet propulsion system.

The removal of reduction gears can be considered only as a temporary solution to the problem. The advent of high speed turbines as the prime mover in submarine propulsion systems leads to only one conclusion—reduction gears will return to submarines. It is therefore of paramount importance that, when installed, these gears be as quiet as our present knowledge can possibly make them. The search for the basic sources of gear noise, the development of isolation techniques, and the strict control of the manufacturing process must continue.

II REVIEW OF PUBLICATIONS ON GEAR NOISE

An analytical review of a large number of articles and papers on the subject reveals no particularly unique proposals for the solution of the gear noise problem. It is generally concluded that the reduction of gear noise can be effected to some extent by intelligent design, rigidly accurate manufacture, and careful installation and operation.

Some understanding of the generation of noise in gears can be achieved by consideration of the factors involved in gear design. In a gear transmission, it is necessary to transmit a uniform peripheral velocity of the driving gear as an equally uniform velocity of the driven gear. The first requirement for this is uniformity of pitch from tooth to tooth. In the case of rapidly revolving gears, it is also necessary to obtain uniformity of transmission during the meshing period of a single tooth; the shape of the tooth and its counter-tooth are decisive in this respect. Essentially, all sorts of curves are suitable for this purpose, provided the curve of one tooth meets certain requirements with respect to the curve of the counter-tooth. Cyclic curves have been found to be particularly well suited, among these the cycloid and the circular involute.

Circular involutes of different base circles are similar to one another, differing only in scale. The latter is given by the radius of the base circle. Two involute gears mesh properly if the common tangent to their base circles (the line of action) and the line of centers (the line connecting the centers of the two gears) intersect at the point of contact of the pitch circles, i.e., the point of action. The involutes themselves are equidistant curves over their entire length; consequently the two meshing gears must have the same normal pitch.

If the distance between shaft centers is changed, the base circles remaining constant, then portions of the involute located at greater or lesser distances from the center are used and meshing takes place at different pressure angles, for example 15°, 20°, and 25°. The normal pitch is not affected, always remaining equal to the distance between involutes (along the line of action).

The teeth must be sufficiently high so that at least one tooth meshes with another until the following tooth establishes contact. This gives a meshing period or degree of overlap equal to unity. If more than one tooth is al-

ways meshing, the meshing period becomes greater than unity, for instance 1.3.

The preceding considerations indicate conditions which must be fulfilled in order to obtain kinematically correct meshing. These are:

1. Uniformity of pitch from tooth to tooth.

2. Equality of normal pitch for gear and counter-gear, i.e., equal pressure angle.

3. Concentricity of teeth with respect to the shaft center.

4. Accuracy of involute over the entire height of the tooth.

5. Equality of tooth thickness.

However, despite meticulous machining and inspection to meet these conditions with the utmost achievable accuracy, gears will still produce noise. The following cause for this phenomenon appears reasonable. A change in direction of sliding motion takes place at the pitch circle. The teeth of the gear enter the spaces between the teeth of the counter-gear with a "bucking" motion, and leave them with a "slipping" motion. Since this bucking and slipping takes place under friction, the change of direction must be accompanied by a shock. Even if an almost mathematically accurate design has succeeded in eliminating shocks caused by flaws in the tooth faces, there still remains the shock caused by direction change of the gear friction at the pitch circle. This series of shocks results in vibration, the frequency of which is a function of speed and number of teeth, and thus of the tooth frequency.

The adoption of the helical gear in marine propulsion systems has done much to alleviate this basic noise generation. Large overlap will by its nature do much to reduce the generated noise. In helical gears this overlap takes place in two ways, in the gears proper inasmuch as the meshing period is greater than unity, and also by virtue of the fact that mesh does not occur instantaneously over the entire width of the gear, but gradually—depending on the helix angle, and in such manner that teeth part contact only after the next pair of teeth have meshed. This overlap depends on the magnitude of the helix angle and on the width of the teeth. If too great an axial thrust is not permissible, then the helix angle must be made smaller and, to compensate, the teeth must be widened. Furthermore, the pitch circle line has a greater significance in the case of the helical gear than in the straight gear; it assumes the load, so to speak, during the entire period of meshing.

To the many requirements a perfect gear must fulfill, one more is added in the case of the helical gear. The helix angle of the gear and counter-gear must be equal and opposite so that the teeth will be loaded over their entire width. This again involves extremely close tolerances.

In the hobbing of helical gears, it is readily possible to lose the noise reduction achieved by changing to this form of gearing. High spots caused by the master gear on the hobbing machine run in continuous bands spirally around the gear across the helices. A helical gear machined in this manner is in actual fact not a helical gear at all, but is converted, by reason of these contact points parallel to the axis, into a spur gear only making contact at a few point along the face of the gear. The load, therefore, instead of being

equally distributed across the whole face of the tooth, is taken on a comparatively small area of each tooth and all the advantages of the helical tooth with its gradual rolling engagement and constant contact are lost.

A set of German destroyer gears which produced excessive noise were investigated by means of polarized light used to produce interference patterns. This investigation revealed tooth errors in the order of four microinches. Small vibrations in cutting operations had introduced these cyclical differences. Fine burnishing of the gear, mated to a master gear, using graphite as the abrasive material, reduced the noise level 10 to 15 decibels.

Another factor which may have influence on the noise output of gears is the type, quantity, and method of application of the lubricant. It can be theorized, for example, that the noise level can be lowered by spraying oil into the gears as they come out of mesh rather than when going into mesh. The reasoning behind this theory is that when sprayed into the mesh, the lubricant forms globules which become wedges between the teeth of the gear and counter-gear. These wedges vary in size and configuration causing variable vibration of the teeth. When sprayed out of mesh, the excess oil is thrown off and the remaining lubricant forms a consistent configuration with respect to the gear teeth. Controlled tests at the U. S. Naval Engineering Experiment Station do not confirm this theory however.

There is an optimum rate of lubrication for most quiet operation; above or below this rate, noise increases. Each set of gears requires a different rate which must be determined experimentally.

The question of lubrication brings up another very probable source of gear noise. In a set of helical gears, the lubricant is pumped between the mating teeth at a very high velocity. This condition is conducive to extreme turbulence. The entrapment of air in solution with the lubricant also presents the possibility of cavitation. Both of these factors are potential sources of noise.

Numerous cures have been attempted to reduce gear noise. Many of these have been successful in some applications and failed in others. A series of experiments with railway reduction gears indicated that noise reduction was possible through the application of damping rings to the inside of the gear rim. However, when such an installation was applied to the gears of the *Panama, Ancon,* and *Cristobal,* the noise level was still such that sleeping in the staterooms was difficult.

In general, the review of publications has shown emphatically that in spite of the vast amount of work which has been done on the investigation and reduction of gear noise, a lack of basic understanding of the subject is prevalent. Because of the numerous variables involved, many investigators have been led to erroneous and contradictory conclusions.

However, all of these publications emphasize the necessity of extreme accuracy in the manufacture and installation of gears. This conclusion is inescapable. Beyond this point there are few proven means of noise reduction applicable to all gears. Until a more fundamental understanding of the basic causes of noise generation and noise transmission in gears has been attained, the generous application of isolation treatment appears to be the only satisfactory solution.

III SUMMARY OF NAVY REPORTS ON REDUCTION GEAR NOISE

The reports on noise investigations of ships' reduction gears can be divided into three groups; the noise survey reports of reduction gears installed in naval vessels; reports of laboratory gear noise investigations and tests run in manufacturers' plant; summary reports and general analyses of the gear noise problem.

Since 1937, noise surveys have been conducted on numerous naval vessels by the U. S. Naval Engineering Experiment Station and by naval shipyards. The surveys were made on widely different types of naval vessels and in different locations throughout the country. Despite this fact, the similarity of test procedures was remarkable. A short review of a few of these reports follows:

Early in 1939, a comparative noise survey was made on the *Yorktown* (CV5) equipped with 45 degree helical angle gearing, and the *Enterprise* (CV6) equipped with 30 degree helical angle gearing, to determine the effect of helix angle on noise output. It was concluded that no concrete difference could be established by such a shipboard test.

The Puget Sound Naval Shipyard conducted surveys of the main reduction gears of several naval vessels in 1944. Tests on the *St. George* (AV16) indicated the necessity of replacing the reduction gears because of their high noise level. The Puget Sound report on the *Commencement Bay* (CVE105) presented the results of several such surveys including *St. George* with the original and replacement gears. A graph of these results is given here as Fig. 1. Noise levels are the average of several stations on the gear cases in decibels above 0.0002 dynes/sq.cm.

As the result of complaints from hospital personnel, noise surveys were conducted on the *Haven* Class ships. The reduction gears of the *Consolation* (AH15) and the *Repose* (AH16) registered excessively high noise levels compared to other vessels of the class. The Engineering Experiment Station designed a damping treatment for the gear casings. This treatment consisted of a laminated assembly of asbestos gasket material glued to the casing, and asbestos wool held in place by ⅛" steel plate retainers. Tests conducted after the installation of the damping treatment indicated that the noise levels of the two vessels had been reduced to a level comparable to that of the other vessels of the class.

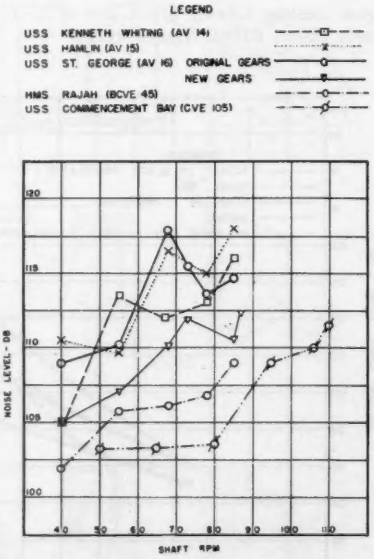


Fig. 1—Airborne Noise Levels of Reduction Gears in Five Surface Vessels

Noise surveys of ships' compartments and main reduction gears were made in connection with the standardization trials of the following vessels: *Saipan* (CVL48); *Midway* (CVB41); *Coral Sea* (CVB43); *Franklin D. Roosevelt* (CVB42); *Philippine Sea* (CV47). The primary objective of these surveys was to provide the Bureau of Ships with the range of noise levels existing in various ships' spaces for the development of noise level specifications. The surveys were also made to determine the sonic suitability of the gears and to provide noise information in connection with the gear development program. The results of these surveys, as given in Fig. 2, show that the ships of the same class or size have comparable noise levels in the area surrounding the main reduction gears. The noise levels given in Fig. 2 are the arithmetic average of measurements taken 1″ from the gear casing. Levels given are in decibels above 0.0002 dynes/sq.cm.

Early in 1942 the Bureau of Ships reviewed all information on gear noise then available. This information included measurements of wideband airborne noise levels made aboard ship and in manufacturers' plants. Two types of shipboard measurement techniques had been used: measurements one inch from gear casing, and measurements at a position midway between the gears of multiple screw vessels. All of the measurements made in manufacturers' plants were made one inch from the gear case.

This review of measurements resulted in a statistical study of several variables expected to affect gear noise levels which included: ratios of pitch diameters to total face width, maximum RPM and horsepower, types of gear arrangements, difference of designers, difference of manufacturers, maximum tooth load per inch of face, pitch line speeds, and gear structure stiffness.

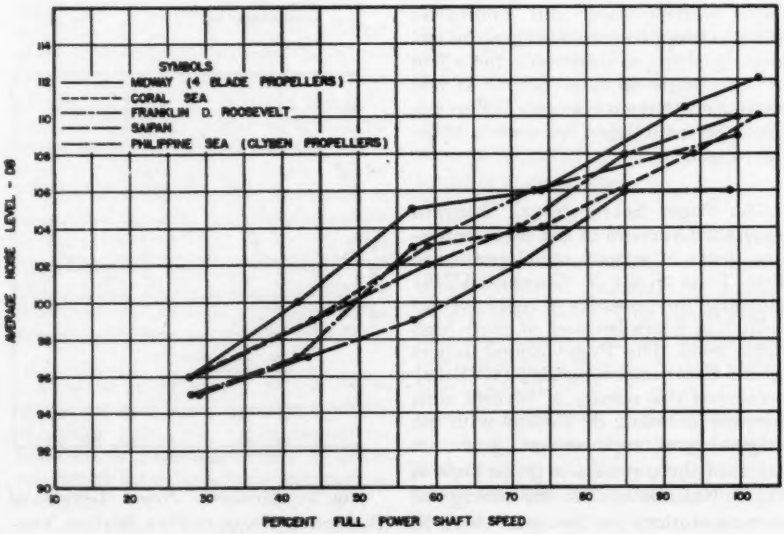


Fig. 2—Airborne Noise Levels of Reduction Gears in Five Aircraft Carriers

Gear structure stiffness was estimated from drawings of the gears which were then listed in order of apparent increasing stiffness. These estimated stiffnesses were designated by the letters A, B, C, and D. The structural designs are shown on Fig. 3. The different gear arrangements in-

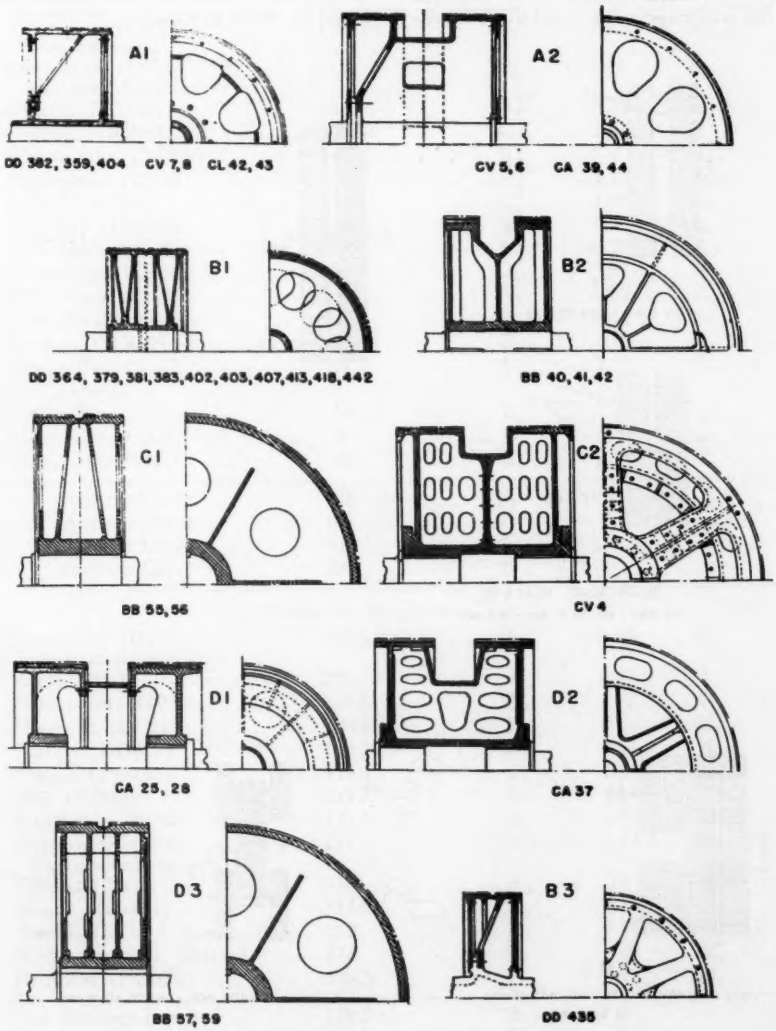
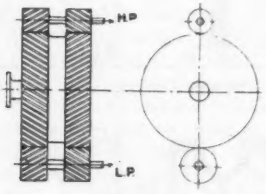


Fig. 3—Types of Main Reduction Gear Structures

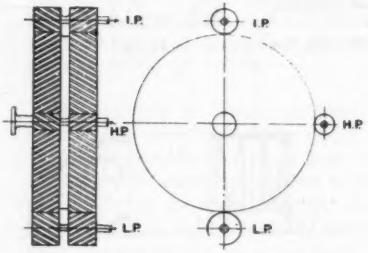
volved in the gears under study are shown in Fig. 4. These are designated M2, N2, Q1, R1, and T1.

Table I lists the vessels for which noise measurements were available, the wideband noise level in db relative to 0.0002 dynes per square centimeter, the type of main gear structure, the ratio of pitch diameter per inch of working face, and the type of gear arrangement. These measurements are listed in three groups:



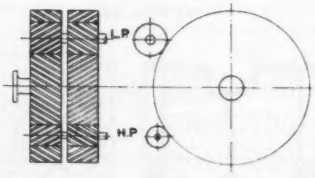
Q 1

CV 5 & 6 CA 25 & 28



T 1

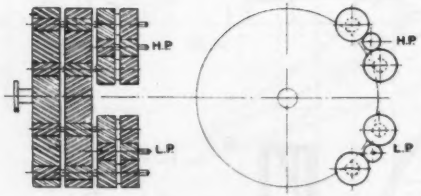
CV 7



R 1

DD 359 & 382 CL 42 & 43

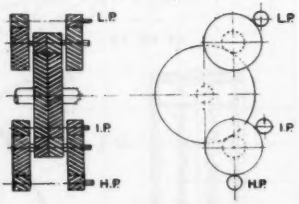
CV 4&8 CA 37 & 44 BB 40



M 2

DD 364, 379, 381, 383, 435, & 442

BB 55 & 57



N 2

DD 402, 403, 404, 407, 413, & 418

Fig 4—Reduction Gear Arrangements

TABLE I

Wideband Noise Level for Reduction Gears at Full Power, Full Speed

Group A—Shipboard Tests

Vessel	Wideband Noise Level in db	Type of Main Gear Structure	P.D. / F.W.	Gear Arrangement
Yorktown (CV5) .... (original gearing)	119	A_2	1.72	Q_1
Yorktown (CV5) .... (replacement gearing)	111	A_2	1.72	Q_1
Somers (DD381)	110	B_1	3.74	M_2
Craven (DD382)	109	A_1	3.2	R_1
Warrington (DD383) .	109	B_1	3.7	M_2
Enterprise (CV6)	108	A_2	1.72	Q_1
Ranger (CV4)	108	C_2	1.76	R_1
Winslow (DD359)	108	A_1	3.15	R_1
Savannah (CL42)	107	A_1	3.56	R_1
Tuscaloosa (CA37) ...	104	D_2	1.67	R_1
Vincennes (CA44) ...	102	A_2	1.59	R_1
New Mexico (BB40) ..	100	B_2	2.61	R_1
Preston (DD379)	99	B_1	3.66	M_2
Nashville (CL43)	99	A_1	3.56	R_1
Salt Lake City (CA25)	99	D_1	1.12	Q_1
Louisville (CA28)	98	D_1	1.12	Q_1
Mahan (DD364)	97	B_1	3.7	M_2
Average Level	108	A		
Average Level	103	B		
Average Level	108	C		
Average Level	100	D		

Group B—Shipboard Tests

Yorktown (CV5) ..... (original gearing)	130.5	A_2	1.72	Q_1
Wasp (CV7)	121	A_1	4.45	T_1
Enterprise (CV6)	120.5	A_2	1.72	Q_1
Mayrant (DD402)	120.0	B_1	2.54	N_2
Sterett (DD407)	119.5	B_1	2.54	N_2
Trippe (DD403)	119.5	B_1	2.54	N_2
Roe (DD418)	118.5	B_1	2.54	N_2
Winslow (DD359)	117.5	A_1	3.15	R_1
Yorktown (CV5) ..... (replacement gearing)	117	A_2	1.72	Q_1
Hornet (CV8)	115	A_1	3.0	R_1
Rhind (DD404)	113.5	A_1	2.41	N_2
Mustin (DD413)	113	B_1	2.54	N_2
North Carolina (BB55)	112	C_1	3.66	M_2
Grayson (DD435)	109.5	B_3	3.7	M_2
Average Level	119.5	A		
Average Level	116.5	B		
Average Level	112	C		

TABLE I

(continued)

Vessel	Wideband Noise Level in db	Type of Main Gear Structure	P.D. / F.W.	Gear Arrangement
	Group C—Shop Tests			
Hornet (CV8)	122.5	A_1	3.0	R_1
Trippe (DD403)	121.5	B_1	2.54	N_2
Roe (DD418)	115.5	B_1	2.54	N_2
Nicholson (DD442)	109	B_1	3.7	M_2
South Dakota (BB57) ..	108.5	D_3	3.77	M_2
Average Level	122.5	A		
Average Level	115.5	B		
Average Level	108.5	D		

Group A: Shipboard tests where one noise level reading only was made at a position either on a centerline between main reduction gears (when two gear sets were located in the same engine room) or three feet inboard of the main reduction gears at the height of a man's head. In the former case, three decibels were subtracted from the wideband noise level to give approximate readings for one reduction gear.

Group B: Shipboard tests where noise levels were the average of levels taken one inch above the gear housings.

Group C: Shop tests where noise levels were the average of levels taken one inch above the gear housing.

Table II, with the same general grouping, lists noise levels versus operating pitch line speed and maximum tooth load in pounds per inch of working face.

The study concluded that no distinct differences in the noise levels of these gears could be attributed to the ratio of pitch diameter to total face width, maximum RPM or horsepower, or the maximum tooth load per inch of face. Neither was there any significant difference which could be attributed to the gear arrangement. Some designers and manufacturers gears were consistently noisy and others were consistently relatively quiet. The differences were not great enough, however, to conclude that any one manufacturer had discovered a panacea for gear noise troubles.

Distinct trends did appear to be attributable to gear structure stiffness and to pitch line velocity. Noise levels tended to decrease with increasing structural rigidity and to increase with pitch line velocity. These trends are shown in Figs. 5 and 6.

These reports give an indication of the concern evinced in excessive airborne noise of reduction gears aboard naval vessels. However the emphasis has recently shifted to the investigation and reduction of structureborne noise. Because of the structural isolation which can be more readily achieved in manufacturers' plants, this approach shows more possibilities for quantitative analysis and correlation with noise in the water than do those limited to airborne noise measurement. A few examples of the post war work in this field are reviewed below.

Noise and vibration tests were made on the main reduction gears of the

TABLE II

Wideband Gear Noise Levels

Vessel	Noise Levels in db	Operating Pitch Line Speed in Ft./Min.	Maximum Tooth Load in lb. Per in. Face
Group A—Shipboard Tests			
Yorktown (CV5) (original gearing)	119	9,920	1068
Yorktown (CV5) (replacement gearing)	111	9,800	1068
Somers (DD381)	110	9,140	1165
Craven (DD382)	109	11,050	1290
Warrington (DD383)	109	9,130	1045
Enterprise (CV6)	108	10,050	1068
Ranger (CV4)	108	7,930	895
Winslow (DD359)	108	10,100	1365
Savannah (CL42)	107	10,072	1305
Tuscaloosa (CA37)	109	9,650	941
Vincennes (CA44)	102	9,450	1010
New Mexico (BB40)	100	6,800	827
Preston (DD379)	99	8,220	1285
Nashville (CL43)	99	10,080	1305
Salt Lake City (CA25)	99	7,690	980
Louisville (CA28)	98	7,690	895
Mahan (DD364)	97	8,160	1285
Group B—Shipboard Tests			
Yorktown (CV5) (original gearing)	130.5	9,920	1068
Wasp (CV7)	121	10,900	1315
Enterprise (CV6)	120.5	10,050	1068
Mayrant (DD402)	120.0	8,350	1495
Sterett (DD407)	119.5	8,320	1360
Trippe (DD403)	119.5	8,160	1495
Roe (DD418)	118.5	8,460	1465
Winslow (DD359)	117.5	10,100	1365
Yorktown (CV5) (replacement gearing)	117	9,800	1068
Hornet (CV8)	115	9,900	1490
Rhind (DD404)	113.5	7,950	1475
Mustin (DD413)	113	8,370	1530
North Carolina (BB55)	112	6,590	1220
Grayson (DD435)	109.5	8,680	1250
Group C—Shop Tests			
Hornet (CV8)	122.5	11,950	1490
Trippe (DD403)	121.5	8,800	1495
Roe (DD418)	115.5	6,360	1465
Nicholson (DD442)	109	8,680	1250
South Dakota (BB57)	108.5	7,140	1200

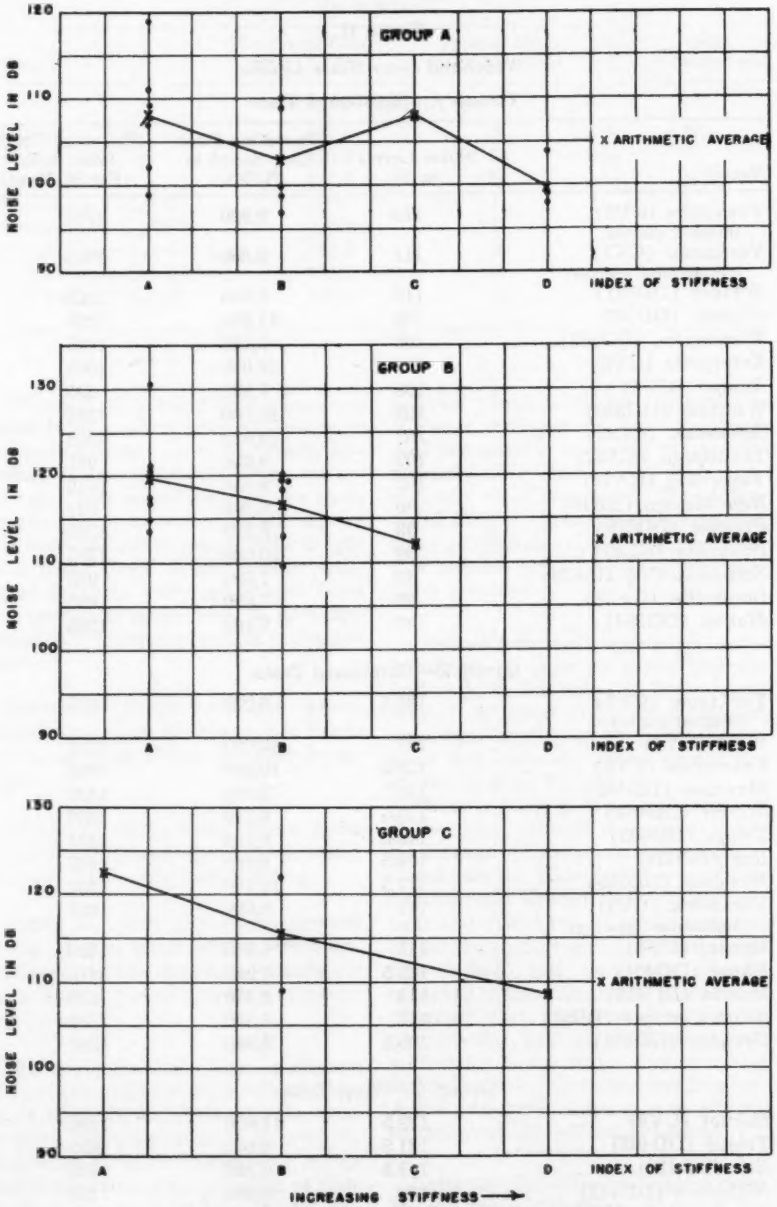


Fig. 5—Noise Level vs. Stiffness of Structure

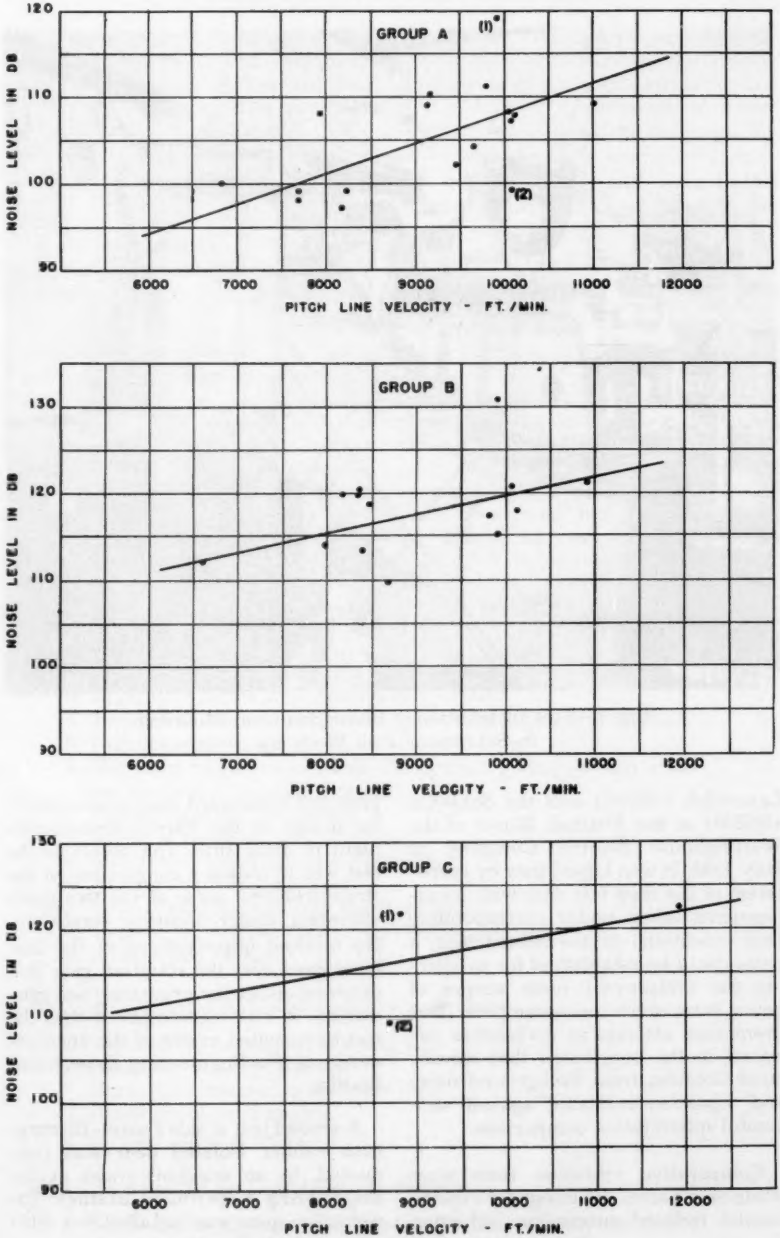


Fig. 6—Noise Level vs. Pitch Line Velocity

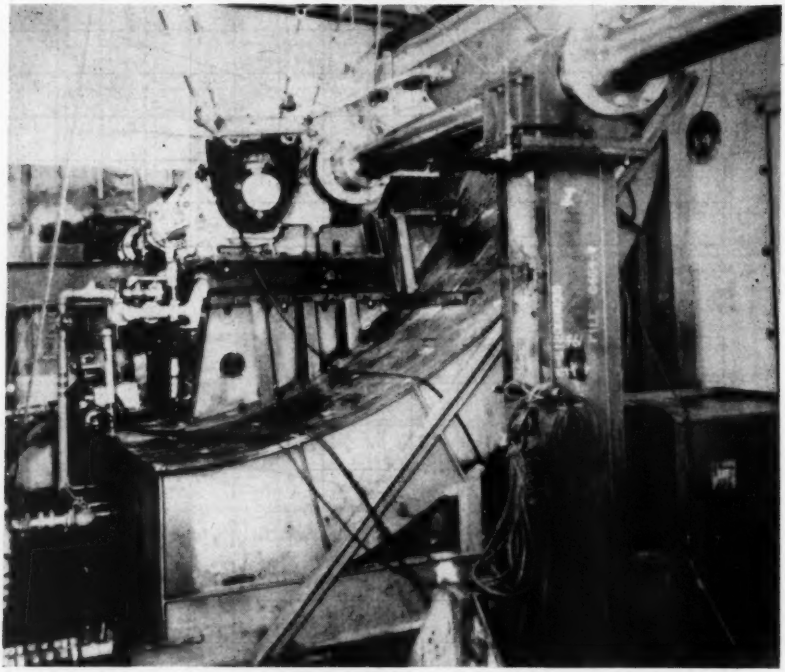


Fig. 7—Test Installation of Reduction Gear Mounted in Submarine Hull Mock-up.

Lancetfish (SS296) and the *Sablefish* (SS303) at the Nutthall Works of the Westinghouse Electric Company in July 1945. It was hoped that by correlation of the shop test data with measurements taken under corresponding load conditions in the submarines, a basis could be established for predicting the underwater noise output of gears from shop measurements. This premature attempt at correlation resulted in the conclusion that insufficient isolation from background noise and vibration militated against successful quantitative comparison.

Comparative vibration tests were made on a Farrel-Birmingham experimental isolated submarine reduction gear and a standard steel gear of similar design at the Farrel-Birmingham plant in June 1946. The object of the test was to obtain a comparison of the structureborne noise of the two gears operating under identical conditions. No marked improvement of the isolated gear over the standard gear was detected under the prevailing test conditions. It was recommended that the test be repeated in one of the anechoic rooms at the Engineering Experiment Station.

A second test of this Farrel-Birmngham rubber isolated gear was conducted, in an anechoic room at the Engineering Experiment Station. The reduction gear was installed in a full-

size, transverse quarter section mock-up of a submarine hull as shown in Fig. 7. The purpose of this test was to approximate roughly the vibratory characteristics of the ship's hull in the vicinity of the gear. The reduction gear and the mock-up were mounted on a 30′ x 10′ x 6′ concrete mat which was isolated from the building vibrations by an air gap surrounding the mat and extending downward the full depth of the mat.

The results of this test were not as successful as anticipated. A large amount of extraneous and unaccountable noise was present. It was indicated that the rubber isolated gear was less noisy than the standard gear, but no reliable quantitative results could be presented. Although these tests did not achieve the stated objective, they provided a valuable lesson in the conduct of laboratory experiments for the determination of the structureborne noise output of mechanical equipment. Simulation of the shipboard structure in the laboratory is impractical. First, the simulated mounting does not vibrate with the same characteristics as the complete hull, and second, the resonant vibrations of the mock-up do not permit accurate measurement of the noise output of the mechanical equipment itself.

It can be concluded from a review of all available publications and studies on the subject of gear noise that very little is known about the relative importance of the various sources of gear noise and what can be accomplished in gear noise reduction. Very probably all possible sources of gear noise have been considered but not evaluated. These possible sources may be summarized as follows:

Factors Controlled by Design

1. Rigidity of gear wheel structures.
2. Type of housing and rigidity of housing structure.
3. Rigidity of shafts and bearings and pinions.
4. Rigidity of connection between gear mountings and ship's hull.
5. Rigidity of teeth.
6. Resonant frequencies within the operating range of any component part of the gear assembly.
7. Operating pitch line speeds.
8. Angle of helices.
9. Maximum operating tooth pressures.
10. Arrangement of gear train.
11. Type of couplings to high speed pinions.
12. Type of bearings and operating clearances.
13. Lubrication system.

Factors Controlled by the Manufacturing Process

1. Precision in cutting tooth profiles.
2. Accuracy of tooth spacing.
3. Periodic errors due to defective hob.
4. Accuracy of helix angles.
5. Surface finish of teeth.

Factors controlled by Installation Technique

1. Accuracy of alignment of bearings, shafts, pinions, and gears.

Factors Controlled by Service Conditions

1. Amount of wear on gear.
2. Type of lubricant.
3. Overloads and overheating.

IV PRESENT BUREAU OF SHIPS GEAR NOISE REDUCTION PROGRAM

Research Program

The present research program in gear noise investigations includes two major phases—the empirical approach and the fundamental approach. The empirical approach involves actual testing of a series of pinions and gears in which material, geometry, finish, and hardness of the component gears are varied. The fundamental approach is designed to give specific information on the basic sources of noise generation in gears.

The U. S. Naval Engineering Experiment Station has erected a 300 KW gear four square test installation, the original arrangement of which is shown in Fig. 8. Provision is made for running the gears and pinions under varying conditions of speed and load. Complete measurements of structureborne and airborne noise can be taken on the sound isolated test gear casing.

The drive motor and speed increases are located in one room and the test gears are located in the adjacent anechoic room. Torque can be locked into the system by the torque applier in the high speed shaft and the exact amount of torque determined from the torque indicator in the low speed shaft. To provide isolation of the test gears from the drive gears, airflex couplings are installed in both shafts and acoustic seals are provided between rooms.

This particular installation had to be modified due to continuing alignment difficulties. As can be seen, the test beds are separately supported and isolated from each other as well as from

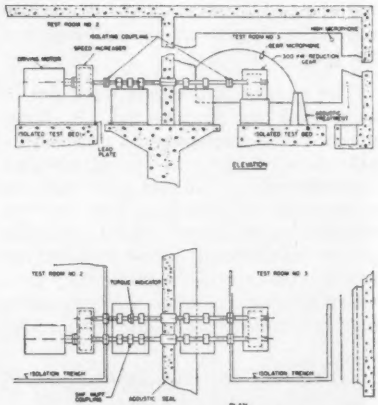
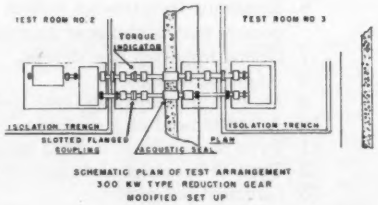


Fig. 8—Arrangement of Original 300 KW Test Installation at the U. S. Naval Engineering Experiment Station.



SCHEMATIC PLAN OF TEST ARRANGEMENT
300 KW TYPE REDUCTION GEAR
MODIFIED SET UP

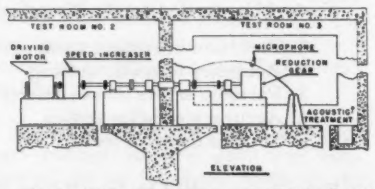


Fig. 9—Arrangement of Modified 300 KW Test Installation at the U. S. Naval Engineering Experiment Station.

the building structure. With the rise and fall of tide in the Severn River motion of the test beds as great as 50 thousandths of an inch occurred.

To alleviate these difficulties, the system has been modified to provide two floating shafts on the high speed side. The ends of these shafts are fitted with half dihedral dental couplings to allow for misalignment. The modified system is shown in Fig. 9. The arrangement of the test gears in the anechoic room is depicted in Fig. 10.

Measuring equipment includes velocity and acceleration pickups on the gear housing structure as well as microphones for the measurement of airborne noise radiated from the gears. This test arrangement permits a quantitative determination of the noise produced by various sets of tests gears under controlled conditions.

The purpose of this particular test is to evaluate the relative noise output of gears in which tooth geometry, material, finish, and lubrication can be varied. Thus, the best combination of these variables can be selected as a guide for future gear procurement.

A more fundamental approach to the determination of the basic sources of noise in gears is to be undertaken in the near future. This involves the construction of a bench test arrangement in which test gears, alignment, relative position of gears and many other factors can be varied in a controlled manner in order that each possible source of gear noise can be studied in detail. The original concept of this test rig is shown in sketch form in Fig. 11.

Applications Program

In parallel with the research program in gear noise reduction, actual installations of noise treated gear sets are in progress. These units will employ many of the measures known and expected to result in quiet gears. These units will be thoroughly noise tested in the manufacturers' plants or in naval laboratories. After installation, structureborne and waterborne noise measurements will be made under all conditions of operation to evaluate the effectiveness of noise reduction measures.

One such unit is a 150 HP creeping drive system basically composed of a high speed direct current motor geared

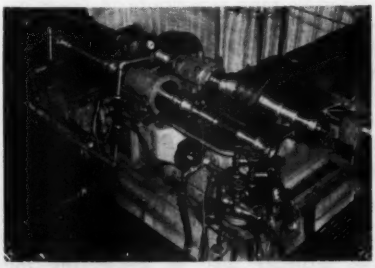


Fig. 10—Arrangement of 300 KW Test Gears in Anechoic Room at the U. S. Naval Engineering Experiment Station

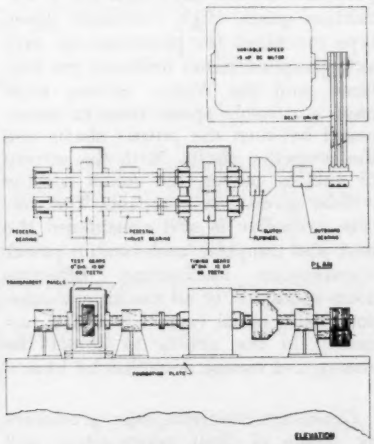


Fig. 11—Sketch of Test Rig for Basic Gear Noise Investigations

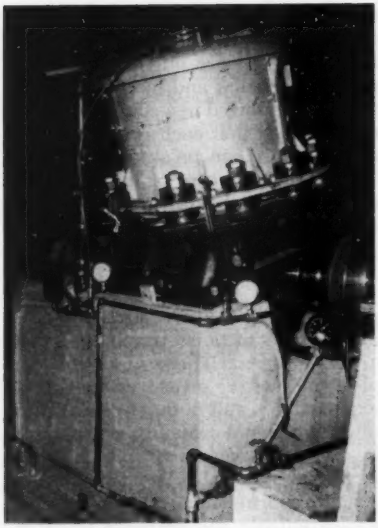


Fig. 12—Creeping Speed Propulsion Unit

to the propellor shaft through a right angle drive. Two test gears have been manufactured—one a hypoid and the other a cone worm. The transmission system is arranged so that the entire assembly is supported on, and transmits power through, rubber in shear, which will reduce motor and gear noise transmitted to the water. This unit, shown in Fig. 12, is being noise and load tested at the Engineering Experiment Station. Modifications will be made in the oil supply, mounts, couplings, and other features of the gear design, as required to reduce noise.

A second series of developments which have been underway for several years involve internal isolation in planetary reduction gears. Some of these units have been installed in operating vessels with reasonable success. Evaluation of these units is continuing and the development details will be reported after completion of the evaluation.

V SUMMARY

Future trends in power plant design point toward the increased use of reduction gears. High rotational speed type machines for primemovers such as high speed steam turbines, gas turbines, and the Walter turbine must have a suitable speed reducer interposed between the output shafts and the propeller shafts. With the advent of nuclear power, the steam turbine will be given new emphasis. The marine propeller is still considered the best and simplest underwater power transmission mechanism. Effective noise reduction of all machinery components in naval vessels is a vital necessity in the ability to detect the enemy and escape detection by him.

Gears are inherent noise producers by virtue of their construction and function. Heavily stressed rotating structural elements, transmitting large loads at high speeds, must produce vibration and its accompanying noise. It has been repeatedly shown that tooth spacing errors and hobbing machine inaccuracies are certain causes of noise generation. Modifications of design and geometry and the use of new materials may contribute to noise reduction; but it is not possible to ascertain their contribution without extensive comparative tests. The gear manufacturer must make use of the most modern engineering methods to reduce errors and thus control the generation of noise at the source.

The Bureau of Ships gear noise reduction program has been set up with the ultimate goal of presenting the gear manufacturer with a qualitative specification which will guarantee the production of gears with a predetermined noise output. These specifica-

tions will definitely set down criteria for minimum machining tolerances, tooth characteristics, special design features, balance, materials, proper lubrication, casing construction, and isolation of components and the completed unit.

An analytical review of this program has been made in light of the numerous suggestions which have been published regarding the causes and correction of gear noise. This review indicates that, if the ultimate goal can be reached, the investigations which have been initiated will eventually lead to a solution. The program is well balanced between basic research, empirical investigations, and practical applications.

The overall problem is extremely difficult. Due to the physical size of the transmissions themselves and their complexity, the investigations will necessarily be both lengthy and costly. However, with adequate direction, effort, and financial support, it is firmly believed that gear noise can be brought under control.

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THE FUTURE OF THE TURBO COMPOUND ENGINE

ACKNOWLEDGEMENT

The May 1954 issue of "Mechanical Engineering" published this article, which was written by Russel R. Mock and Norton B. Jamieson of Curtiss-Wright Corporation, Wright Aeronautical Division, Wood-Ridge, New Jersey.

The relative merits of turbojet versus turboprop versus piston engines as applied to air transports is a question that has been pondered for many years. Fig. 1 is a curve showing the trend of what industry forecasters have been predicting as to the approximate date that scheduled U. S. turbine-transport operation may begin. Some forecasts may have been missed and some slightly misinterpreted, but the general-trend curve is believed to be fairly valid.

As shown by the crosshatched areas, there have been four active forecasting periods since the end of World War II: The first, right after the war; the second, around 1948-1949; the third, in 1952, when the Comet started scheduled operation; and the fourth, in 1953, probably stimulated by active airline study of specific turbine-transport proposals.

As the curve shows, in 1945 it was thought that U. S. turbine-transport operation might start in about 1950. Latest predictions now indicate that it may not start before 1959 or 1960. The trend of predictions, however, is more consistent. The first three points form a reasonable looking trend toward a vertical line which is what should happen as predictions become more accurate. In 1953, however, presumably as the result of reaction to closer studies, an adjustment to this trend appeared. The turbojet prediction was moved ahead one to two years, and a differentiation between jets and props, which began in 1952, became more pronounced. This moved turboprop predictions two to three years farther into the future.

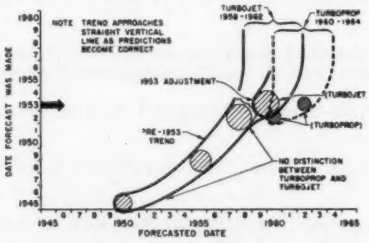

Fig. 1—Trend of preditions on estimated date of initial scheduled operation of U. W. turbine transports.

Extrapolating the area contours of these trends (considering the adjustments) to where they become straight vertical lines, a time range of presumably accurate prediction is formed. On this basis, the ultimate predicted date for the beginning of U. S. turbine-transport passenger operation will fall into the following periods: Turbojet Transport, 1958-1962; Turboprop Transport, 1960-1964.

These are broad predictions, and more specific dates would certainly be desirable. Some current developments would tend to indicate that initial operation, in limited form at least, might begin early in the prediction bracket. Hasty conclusions are not warranted, however, in view of many important factors that could lead toward a more conservative prediction. Some of these factors will be briefly discussed; and to obtain some helpful background and perspective, past accomplishments in developing U. S. commercial engines and transports will be reviewed.

PISTON-ENGINE OVERHAUL-DEVELOPMENT HISTORY

Fig. 2 presents the trend of time-between-overhaul development of Wright Cyclone commercial engines from 1937, when the G-100 and R-2600 were first delivered, to the present. The initial delivery date is indicated under each engine-model designation.

This curve shows that although piston engines have become larger, more powerful, and more complex, the overhaul-period acceleration rates have markedly progressed, and, in general, starting and maximum values have also increased. Whereas the C18BD engine attained 1000 hr. in a matter of three years from initial delivery and is currently authorized for up to 1900 hr., the G-200 took 8½ years to reach 1000 hr. Within the time range of the chart, the earlier engines never did reach this status. The Turbo Compound engine is initiually authorized for 1000 hr. following two sets of three overhauls at 800 and 900 hr., respectively. It has a total accumulated experience approaching 1,000,000 engine-hours and has been in commercial service since June, 1953.

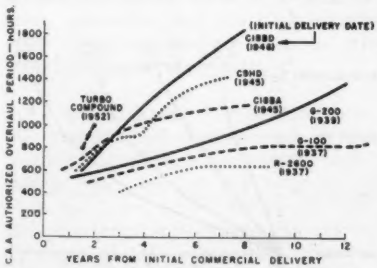

Fig. 2—Time-between-overhaul development history of Wright Cyclone commercial engines.

The progressive piston-engine improvement shown in Fig. 2 over the years is attributed logically to (1) the accumulated experience in designing and developing this type of engine for airline use, (2) the commendable progress made by the airlines themselves in handling the operation and maintenance of these engines, and (3) the accelerated development progress made during World War II.

In regard to turbine-transport engines, some of this experience may still apply, and certainly the military turbine-engine experience is significant. However, taking a purely objective viewpoint, the following facts cannot be overlooked:

1. U. S. airlines have had no direct

experience in operating and maintaining turbine engines.

2. Military experience is largely limited, at least at present, to turbine engines which are relatively simpler and smaller than the majority of those currently contemplated for commercial use.

3. Total military turbine-engine operating time, although large, generally is made up of relatively small accumulations on a large number of engines; thus airline required knowledge regarding high time durability and "wear" characteristics is lacking.

4. The expedient of performing pretime "partial" overhauls, as practiced by the military and the British, may be incompatible to U. S. airlines operationally, economically, or mechanically.

In view of the large investment involved in the turbine-transport venture, and the sensitivity of airline economics and efficiency to engine-overhaul period and trouble characteristics, it is a certainty that the airlines are not underestimating the importance of these factors. They will likely be starting out with relatively new, big, complex engines without the benefit of experience on smaller, simpler engines of the same type. Will the initial turbine engines follow the C18BD curve, or the G-200 curve, or will they be superseded by other engines or models before satisfactorily efficient operation is obtained? These are decision-delaying questions in regard to engines that could cause predictions to become more conservative.

TRANSPORT DEVELOPMENT HISTORY

Past accomplishments in developing commercial airplanes are portrayed in Fig. 3. This shows the development history of several commercial transports, from early 2-engine to recent 4-engine, in terms of development years from final go-ahead to first flight, initial certification, and 50th delivery. To avoid war-activity effects, there were not many validly comparable examples, and some adjustments still had to be made. Nevertheless, although perhaps not totally representative, this curve is believed to be sufficiently indicative to draw some general conclusions.

Paramount is the indication that as transports become larger, more complex, and more expensive, the time required for development becomes greater. Development time of the "Recent 2-engine" airplane was about twice that of the "Early 2-engine," and the 4-engine types took more than twice the time required for the 2-engine types.

To extrapolate these data into the realm of the turbine transport, it is possible to choose ratio factors of gross weight, price, complexity, effort, military-application effect, unknowness, etc., and apply them to the trend. Surprisingly enough, with reasonable variations in these factors—and making

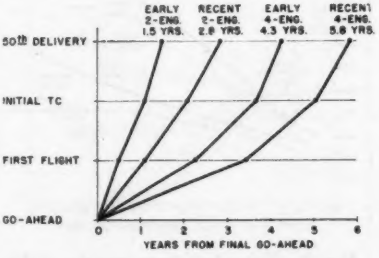

Fig. 3—U. S. commercial transport development history.

the bold and possibly unjustifiable assumption that the noise problem can be solved—the calculated timing for initial U. S. turbine-transport operation will come out generally within the limits of prediction indicated in Fig. 1.

However, there is one important over-all factor that does not show up on the development history chart, but which approaches what is probably the primary crux of the whole situation. This is the question of the money-making ability of the turbine transport, especially the jet.

The examples of Fig. 3 were, of course, restricted to those airplanes which were produced, produced because they were bought, and bought because the buyer was sufficiently convinced that they were money-makers —directly or indirectly, or in one sense or another. Estimating the date of existence of an airplane on the basis of when it could be fabricated or tested, therefore, is not sufficient by itself. It must also sell. The turbine transport may well be a money-maker, but if it is, the airlines are apparently not yet sufficiently convinced of this, and if so, they are unconvinced because of the large number of critical unknowns involved, only some of which have been mentioned herein. Thus, because of these unknowns and the high investment involved, final decision to buy may be considerably delayed.

As we all know, competition from the present and forthcoming British turbine transports is the primary motivating force behind the urgency of U. S. transport development and U. S. airline interest in turbines. Should the pressure of this competition become strong enough, the affected U. S. airlines might be forced prematurely to buy whatever turbine transports are available, be they U. S. or British.

Here again, however, the possibility of this action's taking place depends on many involved and intangible factors which would require comprehensive evaluation. Briefly, these factors are as follows:

1. The competition of British turbine transports will be felt only in relation to the number of them that will be produced and put into direct competitive service with piston transports at any given time. While British production of turbine transports is increasing, that of piston transports, already greater, is also increasing. Moreover, traffic demands have been increasing and are likely to continue this trend. Thus the actual percentage of over-all passenger business that might be lost to British turbine transports during this period of indecision may not be critical.

2. If the economics of turbine transports, existing or in the offing, are at all questionable, the prospects of this being compensated by initially high pay-load factors would be only a temporary remedy. When pay-loads eventually became normal again, the airlines would not want to have a money-loser on their hands. Nor would they desire to charge premium fares on a broad "standard" basis, unless perhaps foreign operators followed suit.

3. Even so, an airline might ordinarily take a chance on an unknown if forced to. However, because of the large investment—much larger than ever before—there will undoubtedly be a strong desire to hold out for a reasonable number of years in order to obtain the best possible airplane.

Therefore, except possibly for those airlines most directly and severely affected by British turbine-transport competition, it is believed that most

U. S. operators will elect to stand by as long as possible—until such time as they are convinced that a truly economic turbine transport can be bought, and until such time as they are financially capable of buying it.

These are not all the issues. But these are some of the important ones which would lead to the belief that the beginning of substantial replacement of piston transports by turbine transports is sufficiently far off to warrant serious consideration of further development of piston engines. And for this reason, it is pertinent to review in a general way, such development potentials that could form the future of the Turbo Compound engine.

TURBO COMPOUND-DEVELOPMENT POTENTIALS

The advent of the Turbo Compound engine provided a new field of engine design. Not only was maximum power increased and specific weight decreased, but substantial reductions in specific fuel consumption were realized simultaneously with higher cruise powers. From the standpoints of airline speed, efficiency, and economy, this places this engine in a favorable position to compete with the turbine engine of the near future and makes serious consideration of its further development possibilities worth while.

The basic approach to increased power can be directed in one or a combination of three channels: (1) Provision of more air to the cylinders, since basic engine power is proportional to air flow, (2) improvement of basic engine efficiency, and/or (3) improvement in efficiency of the power-recovery system.

Formerly, the most direct approach taken was to increase the air supply to a basic engine design. That is, either the number of cylinders or the displacement per cylinder was increased. Typifying this development trend was the Wright Whirlwind series of 7 and 9 cyl., with 108 cu. in. displacement per cylinder, and the Cyclone series of 7, 9, 14, and 18 cyl. having 186 cu. in. cylinder displacement—an increase of 70 per cent. To obtain higher powers than the present 18-cyl. Turbo Compound, this approach would still be possible by either method. However, little change in altitude or economy characteristics would be realized, and additional cylinders or increased cylinder displacement would require changes to the basic engine and turbine structure.

If it is assumed then, that the number of cylinders and cylinder displacement are to remain fixed, some other means of providing more air is required. Cruise powers with a given fuel generally are established on the basis of detonation margin, and present engine ratings are already at the practical maximum for best economy operation. It becomes apparent, therefore, that before increased cruise powers can be realized with the basic engine, the detonation-free range must be extended.

The detonation-free limits in the best-economy range of an engine are largely a function of the air temperature entering the cylinder. In general, a reduction in detonation-limited horsepower of 3 per cent will occur with every 10 deg. rise in intake-air temperature. In the past, this effect has many times limited the extent of supercharging because of the inherent increase in air temperature associated with the pressure rise.

Methods of cooling the super-

charged air, i.e., intake pipe temperatures, have often been studied but as often dropped because of seemingly unacceptable penalties in engine weight and size. More recent studies have shown, however, that such considerations are practicable, provided the increases in power compensate for the penalties incurred. Adaption of a supercharged air cooler, or "aftercooling" system, to the Turbo Compound engine, could be accomplished with relatively minor changes to the basic engine structure. Such changes would be confined primarily to the supercharger section. Cooling units or sections could be mounted adjacent to the cylinders, on or in an extended supercharger section, or perhaps, exist as part of the engine nacelle, with ducting provided between the cooler and the engine. Should this arrangement be feasible, detonation-limited cruising horsepowers could be increased materially.

In addition to raising detonation limits, further benefits of aftercooling would be realized in the form of increased air density. Thus more pounds of air could be "packed" into a given displacement with no increase in supercharged air pressure. This would be especially effective in increasing cruise altitudes as well as cruise powers. Moreover, since power recovery of the Turbo Compound engine is primarily a function of mass gas flow, further increases in recovered power could be anticipated.

Concerning improvements in basic engine efficiency, these are, of course, continually under constant consideration by all aircraft-engine manufacturers. Years of investigation on cams, cam overlap, cylinder porting and valving, compression ratio, spark advance, and basic fuels are in the files. It is safe to assume that current engines reflect the results of this accumulated research and this is particularly true in the case of the Turbo Compound engine.

One of these items, variable-overlap cams, is still worthy of particular consideration. Cam design in respect to overlap between intake and exhaust valve opening is, of necessity, a compromise between the requirements at maximum power and those of cruise power. Variable-overlap cams could provide optimum overlap in each power range. This provision would involve mechanical problems, but would improve engine economy.

Any speculation on the future of the Turbo Compound engine should include methods of improving or augmenting the power-recovery system since utilization of exhaust energy in the current engine still falls short of the actual usable power available.

The design of the current blowdown turbine nozzle was of necesity based on high gas flows, with exit-area reduction minimized to avoid back pressure. This incurred an unavoidable reduction in exit velocity in the cruise range, with a corresponding decrease in power-recovery percentage in this range. This situation could be alleviated by a variable-exit-area nozzle and, coupled with a variable turbine-to-engine drive ratio, could provide a more constant percentage of power recovery throughout the entire power range.

To provide additional power recovery at altitude, a pressure turbine could be combined with the present Turbo Compound engine to effect a double-compounded blowdown and pressure-turbine system. In such a system, the exhaust gas would first "blow down" to approximately sea-level pressure through the blowdown turbine and, when at altitude, the ex-

pansion could be completed through the pressure turbine. Theoretically, such a combination would not increase back pressure on the basic engine. The problems incurred during development of such a configuration might be considerable, but the altitude power benefits would be attractive.

CONCLUSION

These are some of the ways the Turbo Compound engine could be further developed prior to turbine-transport application. The particular method to be pursued depends largely on the timing and performance requirements to be fulfilled.

SHIPBOTTOM PAINTS

Past, Present and Future Research and Development on Anticorrosive and Antifouling Shipbottom Compositions

W. J. FRANCIS

THE AUTHOR

graduated from Cooper Union Institute of Technology, New York, as a Chemical Engineer. Took post-graduate work in physical chemistry at Columbia University. Received degree of Bachelor of Science in 1930 and of Chemical Engineer in 1934. Has been granted a U.S. patent for a hot plastic anti-fouling ship bottom paint. Has been employed at the Norfolk Naval Shipyard, in the Paint Laboratory since January, 1939. Is now a Paint Technologist and Head of the Paint Laboratory. Is a member of the American Chemical Society and Chairman of its Hampton Roads, Va. Section.

The ingenuity of sea-faring men has been challenged by the fouling problems ever since man took to boats. Probably one of the earliest attempts to defeat the ship-worm and the barnacle was made by Archimedes who sheathed wood ship bottoms with lead fastened with copper nails. This method gave some protection but didn't prevent fouling. Earlier vessels had been coated with tar, pitch, grease, guano and various other mixtures in attempts to keep their bottoms clean. During the last hundred years or so many patents have been issued for antifouling coatings including all sorts of material such as phenols, cyanides, creosote, garlic, tobacco juice, strychnine, compounds of arsenic, mercury, copper, lead, zinc, etc.—all more or less unsuccessful.

Wooden ships were sheathed with copper for the best protection. When iron ships first came into use about 1860, the problem of preventing fouling became more difficult because the related problem of preventing corrosion now presented itself. Sheathing iron ships with copper proved impractical and costly. The search was intensified to develop a satisfactory shipbottom paint system comprising an antifouling paint which would afford good protection against fouling and an anticorrosive paint to act as a barrier coat between the metal surface and the antifouling coat.

As late as 1900 U. S. Naval ships were being sheathed with wood and copper. Trial and error experiments with empirical mixtures in commer-

cial bottom paints were giving erratic and unsatisfactory results. With the advent of iron vessels, the Navy Department realized the necessity of a more systematized approach to the problem of protecting shipbottoms from corrosion and fouling. At the request of the Secretary, the Navy started research on shipbottom paints in the Norfolk Navy Yard about 1906. Two years later the Norfolk Navy Yard started manufacturing shipbottom paints based on shellac spirit varnish as the vehicle or binder. The anticorrosive paint was pigmented with zinc dust and zinc oxide. The antifouling was pigmented with zinc oxide, Indian Red, and mercuric oxide. These formulations and similar ones in which Yacca gum replaced part of the shellac were successfully used by the Navy until 1926. By 1920 the total yearly quantities of the shipbottom paints made at Norfolk and Mare Island Navy Yards were approximately 103,000 gallons of anticorrosive and of antifouling. However, there were several disadvantages in the use of the shellac formulations. Shellac was an imported product of uncertain supply which might be cut off in war time, and was subject to great price changes. The quality of shellac was quite variable, and no methods were known for determining the characteristics needed to produce the best results in paints. Alcohol, as a solvent, was quite expensive as compared with hydrocarbon solvents used in other forms of spirit varnishes. Mercuric oxide, the toxic component of antifouling paint, was very expensive, often of inadequate supply because it was mainly of foreign origin and was also extensively used in European antifouling paints, and was dangerous to use because it was poisonous.

With the foregoing considerations paramount, the Bureau decided about 1922 to initiate a broad investigation of the fouling of ships, the effect of fouling on the resistance to propulsion, and the best raw materials, preferably of domestic origin, to use in ships' bottom compositions.

In 1926 the Navy abandoned the shellac bottom paints, and started the manufacture and use of the newly developed rosin-coal tar bottom paints. Formulas 14RC and 15RC became the standard anticorrosive and antifouling paint respectively. Formula 14RC contained rosin/145 lbs., coal tar/47.5 lbs., manganese linoleate/129 lbs., coal tar naphtha/380 lbs., zinc oxide/186 lbs., Venetian red/93 lbs. silica/93 lbs. Formula 15RC antifouling contained rosin/248 lbs., coal tar/63 lbs., pine oil/39 lbs., coal tar naphtha/338 lbs., zinc oxide/238 lbs., silica/78 lbs., magnesium silicate/72 lbs., cuprous oxide/145 lbs., mercuric oxide/45 lbs. Formula 16, comprising gum shellac, pine oil, alcohol, zinc oxide, Indian Red, cuprous oxide, was the antifouling paint used on wooden-bottom vessels.

The coal tar-rosin type paints were used up until about 1940. They had certain advantages over the shellac paints in several respects. They were less dependent on foreign sources for raw materials, were cheaper and did not deteriorate as rapidly on exposure to air and could be applied without considering the undocking time of the vessel as critical. The coal tar rosin paints were not very durable, however, and did not possess good erosion resistance properties. Coal tar, used as a plasticizer for the rosin film, was not found very satisfactory. Numerous modifications of formulae were made by substituting various oils for the coal tar plasticizer, but the substitutes proved deficient.

The practice of painting ship bottoms until 1940 was to clean the hull by scraping and wire brushing all loose

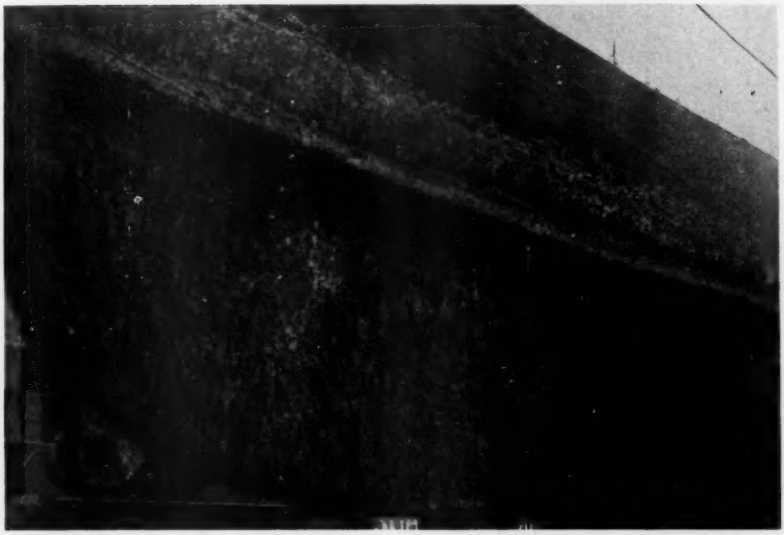

Fig. 1—Port Bow of Attack Transport, showing heavy fouling and rust after one year's service with poor paint.

paint and corrosion and applying one coat of Red Lead primer, Formula 9, then two coats of anticorrosive Formula 14RC, and one coat of antifouling Formula 15RC. A good bottom paint job would last about nine months.

By 1940 a drastic change took place in shipbottom painting. The old formulations were discarded and the hot plastic paints came into use. Research and development in the Naval laboratories resulted in a much more durable bottom paint system that dried fast enough to permit the undocking of a ship immediately after the application of the hot plastic antifouling coat. A new anticorrosive, Formula 14, based on phenol-formaldehyde modified rosin varnish containing a chromate type of pigment comprised the undercoat part of the system. Standard Formula 14 for 100 gallons contained 613 lb. phenol-formaldehyde resin, 98 lbs. manganese linoleate, 35 lbs. coal tar, 87 lbs. load chromate, 175 lbs. zinc oxide and 87 lbs. silica. The phenolic resin vehicle (100 gals.) contained phenol 45 lbs., formalin 54 lbs., lead acetate 27 lbs., gum rosin 360 lbs., and coal tar naphtha 408 lbs. The vehicle had a solids content of 48-50% and a viscosity slightly less than Tube A (Gardner-Holdt).

The hot plastic antifouling paint comprising the topcoat part of the paint system, evolved as a result of work started by the Navy about 15 years previously or about 1925. Hundreds of compositions were formulated and tested, based on mixtures of natural and synthetic resins, heavy metal soaps, oils, pitches, waxes, and fatty acids as matrices incorporating various toxic components and pigments.

Formula M.I. 42 hot plastic antifoul-

Fig. 2—Hot plastic shipbottom paint on Attack Cargo Ship after two years' service.

ing was first applied to Naval ships as standard practice in 1940. It was a reddish brown colored thermoplastic solid, hard and brittle at room temperature and melted at about 120°F. It contained phenol-formaldehyde resin, rosin, paraffin, cuprous oxide, mercuric oxide and arsenic. It required heating to about 300°F. for application. Special kettles, spray guns and electrically heated rubber hose were designed for spray application. The hot plastic could be applied in a one-coat application to give a 30 mils thick film (about ten times the thickness of the orthodox paint film). The material dried as fast as it was applied, giving a thick highly water impermeable film with good water erosion resistance and having a toxic reserve calculated as sufficient to last about ten years provided the coating did not fail through cracking and loss of adhesion.

Further Laboratory study of the hot plastic composition revealed that cuprous oxide was the most important toxic ingredient upon which the antifouling efficiency of the composition depended, and that the arsenic and mercuric oxide components were contributing very little benefit from the antifouling standpoint. The formula was modified first by omitting the arsenic which proved to have practically no repellent action against marine organisms. Then mercuric oxide was eliminated from the formula because it was found that this expensive ingredient was decomposing during the manufacturing process of the hot plastic, leaving metallic mercury in the bottom of the heating kettles. The elimination of arsenic and mercuric oxide was reflected in the change in formula in 1942 and the adoption of Formula 15HP which contained cuprous oxide as the sole toxic ingredient.

Another change took place about this time in the type of primer used on underwater steel hulls. Red lead

primers, Navy Formulas 1 and 9, were found to give poor performance under sea water immersion conditions. The red lead primer softened under water and caused loss of adhesion of subsequent coats of shipbottom paint. An all purpose zinc chromate primer based on a combination vehicle of 100% phenolic resin varnish and a long oil soy bean oil modified alkyd resin, Formula 84, was adopted as the standard primer for metal of underwater and topside and interior surfaces. The advantages of zinc chromate primer as compared with red lead primer embodied its quick-drying properties, versatility in being suitable over aluminum as well as steel, its lighter coating weight, lighter color, better durability and adhesion in a thin coat, lower cost, and the relatively new concept of using an inhibitive type of pigment, zinc chromate. Zinc chromate is slightly water soluble, and when water penetrates the zinc chromate paint film to contact the metal surface, some of the chromate ion is set free so that it depolarizes or passivates the metal, thus preventing corrosion of the metal surface.

Zinc chromate primer did not prove very satisfactory as an underwater primer under ship service conditions. The primer coating failed early by blistering and causing disruption of the anticorrosive and antifouling coats. Consequently in 1943, Formula 84 primer, was removed from the shipbottom paint system, but was retained for use on hull surfaces above the waterline, all exterior topside surfaces and interior surfaces.

Starting from late in 1943 the standard Navy practice in maintenance painting of shipbottoms was to apply two coats of anticorrosive paint, Formula 14, to the hull cleaned by sandblasting to bare metal, and topcoating with one coat of hot plastic antifouling 15HP or with two or three coats of cold plastic antifouling Formula 143E or 65-5F. The cold plastic paints were used when it was not feasible to apply hot plastic. Hot plastic could not satisfactorily be applied during cold weather at temperatures below 40°F. The cold plastic could be applied during cold weather and did not require any special heated spraying equipment. The cold plastic type paints were developed by the Naval laboratories in 1941 to provide a cheap, easily applied anti-fouling, one not having the inherent application difficulties of hot plastic which required expensive equipment, more highly skilled operators, and was critical relative to the sprayability temperatures and ambient air temperatures. The two cold plastic formulas were different in composition. Formula 143E had a phenol-formaldehyde resin and chlorinated rubber vehicle pigmented with cuprous oxide. Formula 65-5 had a rosin-soft coumarone-indene resin vehicle and a pigmentation of cuprous oxide, mercuric oxide, Indian Red and talc. Both were liquid paints containing coal tar naphtha as the volatile solvent and dried in several hours. A two-coat application required a minimum of four hours before undocking a vessel, and the antifouling coating had a useful service life of about one year.

The hot plastic antifouling was so far the most durable shipbottom coating developed. The interval for docking ships for repainting was extended from nine months to two years. On inactive ships hot plastic has given good protection for five years. However, the hot plastic still had certain deficiencies. It had a tendency to crack under cold conditions, and to sag and flow, resulting in a rough film, under hot summer weather conditions. Cracks in the hot plastic permitted corrosion to occur in the cracks and a sagged uneven film left some areas in-

adequately protected and caused increased resistance to propulsion of the ship.

During the mid-World War II period the Bureau of Ships requested further intensified effort of the Naval laboratories to develop an improved hot plastic antifouling paint designed around a combination of the best characteristics of the hot and cold plastic paints and durable enough to last five years on a shipbottom if a prolonged period between drydocking was necessary. The Bureau gave the following criteria for characteristics of an improved non-solvent, hot melt type antifouling composition:

1. Have low viscosity in the molten state at temperatures between 200 and 300°F. for easy spray application.

2. Be stable and non-reactive in reducing kettles while the material is being heated for application.

3. Have self-levelling properties to give a smooth film.

4. Good sag resistance at temperatures up to 140°F.

5. Be flexible, as well as insensitive to thermal and physical shock.

6. Have satisfactory application properties at air temperatures as low as 32°F.

7. Be crack-resistant at air temperatures as low as 0°F.

8. High specific adhesion to all types of anti-corrosive paints, as well as directly to steel.

9. Impermeable and non-absorptive in seawater.

10. High water erosion resistance.

11. Adequate matrix solubility and copper leaching rates for maintenance of fouling resistance after repeated alternate exposure to seawater and air.

A new improved sag-resistant hot plastic with most of the desired physical characteristics just mentioned was developed by the Norfolk Naval Shipyard after about eight years of experimental laboratory work and service testing. In 1951 Formula 15HPN became the new standard Navy hot plastic. Norfolk started manufacturing the hot plastic for Naval use in November 1951. This composition contains 62.12 per cent solid vehicle as rosin, high melting paraffin and ceresine waxes and copper linoleate and 37.88 per cent pigment as cuprous oxide and magnesium silicate.

Concurrent with the development of the new hot plastic was that of a superior anticorrosive shipbottom paint. Norfolk Experimental Formula 55-54 became Navy standard Formula 14N in 1951. This composition has a short oil phenolic-coumarone-indene resin varnish vehicle with a zinc chromate base multiple pigment. This anticorrosive is readily applied by brush or spray, dries in a couple of hours, has excellent adhesion to metal and much better durability than earlier formulations, inhibits corrosion for longer periods of time, and serves as an excellent substrate for topcoating with hot or cold plastic antifouling paints. In fact, this anticorrosive has shown outstanding merit in comparison with other Navy and commercial anticorrosive and primers, even in applications made over rusted steel under extreme marine atmospheric conditions.

Another new development in the shipbottom coating system was put into practice in 1951 with the introduction of the vinyl wash primer as the pretreatment for sandblasted steel prior to the application of the anticorrosive and antifouling paints. The Wash Primer, Formula 117, was a World War II development resulting from a Navy project carried out by the Bakelite Corporation through the Na-

Fig. 3—Vinyl hull paint after 2 years' service on a Destroyer.

tional Defense Research Council. The "Wash Primer" pretreatment superseded the former Navy practice of washing down underwater hulls with a 5 per cent phosphoric acid solution following sandblasting. Wash primer composition contains phosphoric acid and zinc chromate in a vinyl butryal resin and alcohol solution. It dries in 10-15 minutes to a tough and very adherent thin film, promoting improved adhesion for subsequently applied paint systems.

The present Navy practice for protecting shipbottoms consists of the application of one coat of Formula 117 Wash Primer to give a 0.5 mil film thickness, then three coats of Formula 14N anticorrosive giving a 4.5 mils film thickness, followed by one coat of Formula 15HPN antifouling hot plastic at 25 to 30 mils film thickness. As an alternate to the hot plastic, three coats of cold plastic antifouling, Formula 105, are applied to produce a 10-12 mils thickness of film. The present shipbottom hot plastic paint system has thus far proven the most durable and satisfactory organic protective coating for Naval vessels and is believed to be superior to any in use by the world's navies. The formulas for the Navy's shipbottom paints were considered important war-time secrets, and these compositions (except one) have only very recently been publicly disclosed. Ships can now stay at sea longer than two years without suffering from the consequences of fouled and corroded bottoms.

Future developments for the improvements of shipbottom compositions are directed toward the use of the newer synthetic non-saponifiable polymers or resins—the vinyls—as the medium or binder for the various pigmentations. The vinyl paints are thin bodied liquids, easy to spray and dry

Fig. 4—Norfolk Naval Shipyard's Hampton Roads Exposure Test Racks for bottom paints at Norfolk Naval Base.

in less than an hour. Their films are quite impermeable to water, highly resistant to alkalis, acids, oils and many chemical contaminants. They produce very smooth films of excellent erosion resistance. Unlike many underwater paints, they are quite resistant to cracking and checking under conditions of alternate sea immersion and air exposure. The vinyl shipbottom paint system comprises the vinyl metal pretreatment (Wash Primer) Formula 117, Vinyl Zinc Chromate Primer Formula 120, or Vinyl Red Lead Primer, Formula 119, and Vinyl Red Antifouling, Formula 121. The seven coat paint system is applied to give a total minimum dry film thickness of about 9.5 mils. The Bureau of Ships has an extensive service test evaluation of the vinyl paint system currently underway on over seventy vessels. The results from inspections of vinyl paints on these shipbottoms are now being assembled and studied and will probably be largely completed within the year. The performance results appear promising but it is still too early to draw definite conclusions.

Another aspect in the future development of better shipbottom coatings embodies the idea of using a hot plastic type of anticorrosive nearest the metal to prevent corrosion more effectively and subsequent failure of the antifouling topcoat. The objective is to apply a thick film of the non-solvent hot plastic type of anticorrosive nearest the hull surface and then cover the anticorrosive with a relatively thin film of antifouling paint. Maintenance of the thick film hot plastic anticorrosive should be unnecsesary over longer periods of service, while the antifouling paint coating could be quickly renewed at each docking. An experimental anticorrosive formulation of the hot plastic type has been

developed at Norfolk and it is expected that a ship service test will be started in the near future.

Future research and development in organic protective coatings for ships' bottom and other underwater structure will take more cognizance of cathodic protection as a valuable method of preventing corrosion. It now seems obvious that a good underwater paint system in conjunction with a suitable cathodic protection system (either with sacrificial anodes or impressed current) will be a great step forward in the solution of the problem of preventing corrosion and extending the service life of metal in seawater. Paints will be required to withstand the effects of electric currents flowing from the anodes to the ship's hull cathode. The protective paint film will therefore require electrical resistance, water impermeability, adhesion and alkali resistance to a high degree.

Considerable research efforts of paint technologists are being applied towards the improvement of shipbottom paints to decrease their susceptibility to film failure due to cracking, peeling, embrittlement and loss of adhesion during the drydocking of a ship. Such coatings should be capable of repeated drydockings and the consequential exposure to the atmosphere without requiring renewal or extensive touching-up of the coating. Relatively hard, tough, smooth chemical and water resistant films of the vinyl copolymer type should offer excellent possibilities for the development of coatings with the desired aforementioned features.

For the long term preservation of vessels of the Reserve Fleet, the Navy is now seeking a shipbottom protective coating system that will last for about fifteen years. This would result in enormous savings in the costs of maintenance painting for inactive vessels.

The boottopping belt or waterline area is the most abused outside surface of a ship. Alternate exposure to

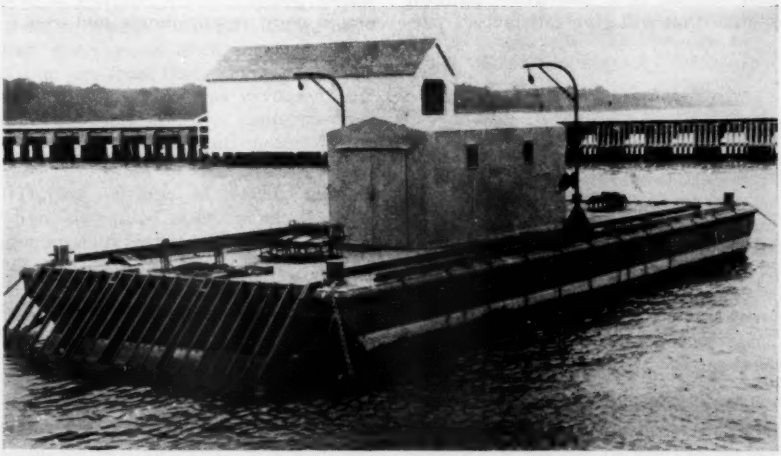

Fig. 5—Navy Paint Test Barge, used for fouling exposure testing of bottom paints in the York River at Naval Mine Depot, Yorktown, Va.

salt air and immersion in sea water, together with water erosion and the abrasion of fenders and debris, destroys any but the toughest and most waterproof paint film. A boottopping paint should also have good antifouling properties to prevent fouling at the waterline by marine growths, especially by algae (seaweeds). A better black antifouling boottopping paint has been developed and put into use, but further development is underway to produce a superior coating based on tougher synthetic resins of the vinyl type.

While we pursue the course of developing better shipbottom coatings, their technology is becoming more complex and their proper use and application requires more technical know-how. We stress the need for good surface preparation and idealistic conditions for paint application in order to secure the optimum results from their service performance. However, we must not lose sight of the fact that ideal conditions for shipbottom painting ars rarely obtained. What is still needed is a fool-proof painting system that will give satisfactory performance in spite of non-ideal conditions for application.

It might be said that until rather recently we have largely depended on paint coatings to protect man's structures, whether they be ships, houses or machines, from deterioration by nature's basic elements, according to the science of the ancient Greeks—earth, air, fire and water, but now we may have to rely on newfangled synthetic coatings to provide the additional protection against contamination by numerous man-made radio-active elements, toxic gases and chemical debris. With so many novel and divers materials and techniques, new ideas and changing requirements for use and performance coming into being at a rapid rate, technical research and development in the protective coating field is an increasingly complex process in the constant struggle to meet the challenging rate of progress. It is difficult to say just what the future demands in paint technology will be, but such a startling development as the nuclear powered submarine certainly shows possibilities of starting a new era in paint requirements and uses.

NEW DEVELOPMENTS IN THE HULL DESIGN OF WOODEN SHIPS

ACKNOWLEDGEMENT

This article is an abridged version of a paper presented before the Chesapeake Section of The Society of Naval Architects and Marine Engineers on 26 February 1953. The author is Mr. A. Meredith Johnson of the Hull Design Branch of the Bureau of Ships. The paper discusses the advanced construction features of a modern large wooden minesweeper, particularly the extensive use of adhesive laminated frames and beams, the relatively light double-diagonal planking system, the absence of traditional framing practices, and the extensive use of wood preservative treatment.

The modern naval architect thinks in terms of steel for the hulls of all but small craft. Wood as a construction material for ships has been relegated to minor items such as decorative finishes, partitions, furniture, cargo battens, dunnage, or deck covering. This is a far cry from that era 100 years ago when the position was reversed and iron products merely supplemented wood, the principal hull material.

During periods of world conflict when demands upon steel became greater than resources or manufacturing capabilities, wood assumed renewed importance in the shipbuilding industry, but it's rise was short and fleeting. Furthermore the transient nature of wood shipbuilding programs during these times of frantic emergency was generally detrimental to the reinstatement of wood as a prominent shipbuilding material. Design was often wasteful of material, ships were hastily constructed, and little attention was given to preservation. The direct consequence was that wood fell in even more ill repute among the naval architects.

Wood is one of the most abundant natural resources this country possesses. Were the material inherently weak and worthless for construction purposes no concern would be felt for its lack of use. The fact of the matter is that wood, on a strength-weight basis, is one of the strongest materials known to man, having a specific strength over three times that of steel. For example, the bending strength-specific gravity ratio of Douglas fir is 24400 while the same ratio for steel is only 7650, and the weight of wood compared with steel for sections of equal strength in bending is only 15 per cent.

Design in accordance with classification rules is often wasteful of the basic material, especially in view of its superior strength-weight qualities. The present scantling rules seem to be

based more upon a theory of strength through mass than utilization of inherent capabilities. The greatest limitation in the use of wood is the relative weakness of joints and fastenings. Classification rules attempt to cope with this limitation by the use of mass and brute strength. The problem can now be more effectively overcome through utilization of modern manufacturing techniques and new developments in the art of wood fabrication.

EARLY DESIGNS

The history of wooden ships reveals that 100 years ago, when construction with this material was at its peak, many interesting features were incorporated in design. Planking systems were varied and, by present standards, unusual. In many cases layers of planking were laid transversely, diagonally, and fore-and-aft, all in the same vessel. Frame spacing in large vessels was as much as 60 inches and heavy longitudinal members were almost non-existent in many designs. For instance, one of the series of royal yachts *Victoria* and *Albert* (1) was 338 feet overall length, of 40 feet beam and displaced 2345 tons at a draft of 16 feet. Her outer skin consisted of diagonal planking covered by fore-and-aft planking 3 inches thick. This planking system was supported by double-sawn frames spaced 60 inches. She was launched in 1855 and saw at least forty-four years of useful service.

Another unusual design was the 700 ton clipper ship *Vision* (1) with frames sided 8 inches, molded 6 inches and spaced 56 inches. Planking consisted of a transverse course 1-⅜ inches thick, followed by two 1 inch diagonal courses, and finally the outside planking of 4-½ inch red pine laid fore-and-aft. The only longitudinals used were keel, single keelson, and light clamp and shelf. Numerous examples of similar designs occur in history, but the two cited are sufficient to illustrate the retrogression of wood ships design during the past century. The challenge is to break free of traditional construction, study the teaching of the masters of a century ago, and progress from there to constantly improve and refine designs in wood.

CONVENTIONAL DESIGN

The midship section illustrated in Figure 1 is a typical example of wood shipbuilding in accordance with classification rules. Continuity of strength is achieved by overlapping of a series of separate pieces of wood with component parts of the vessel mutually supporting and clamping each other. Because of the lack of continuity of individual members, strength is achieved only by piling piece upon piece until an uneconomical mass is the result. The frames are sawed from planks and in order to eliminate cross grain the planks must be a series of short sections oriented to the shape of the frame. Since these pieces cannot be attached together endwise, other shaped pieces are laid to act as buttstraps and are in turn supported by the first piece. The frame thus becomes a series of sections called floors and futtocks, each mutually acting as buttstraps for the other. The frame of Figure 1 consists of two sets of sawed timbers each set being made of planks 11-½ inches thick. Any semblance of continuity of strength through the frame must re-

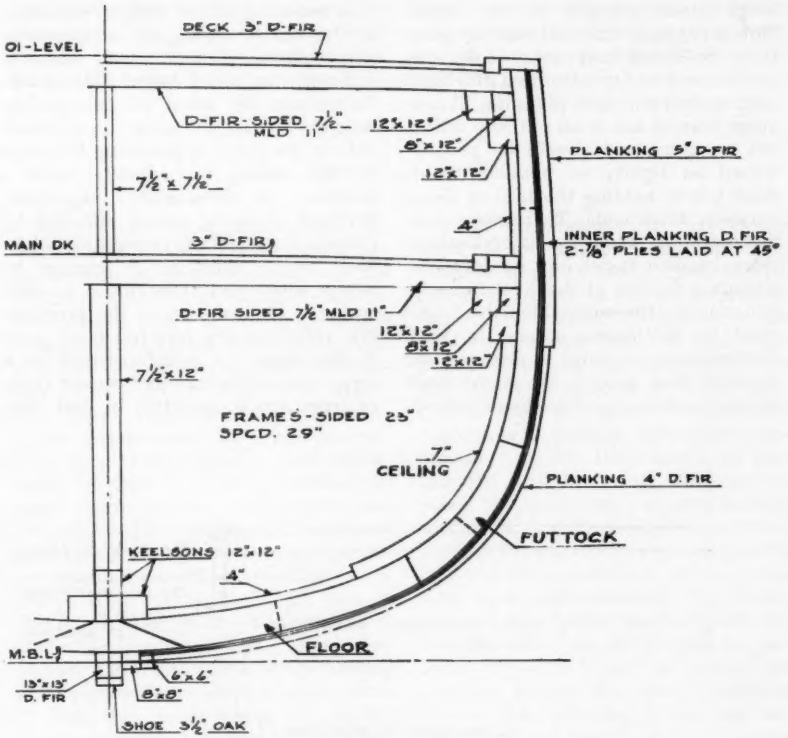

FIGURE 1

SCANTLINGS BASED ON CLASSIFICATION RULES

sult from a dubious system of short pieces of wood and the fastenings connecting them. To insure that the frame holds together an inner skin called ceiling is introduced so that the frame may be clamped between it and the outside planking. In order to assure transverse strength at the keel, massive longitudinal timbers called keelson, sister keelson, and rider keelsons, and transverse members called floors are, together with the frames, bolted together into one mass of lumber. Transverse strength at the intersection of a deck beam and shell frame is achieved in similar manner by means of heavy clamps and shelves connected to frames, beams, ceiling, deck planking and to each other. In lieu of the clamp and shelf construction, the classification rules will allow massive knees fastened between shell frame and deck beams.

A large proportion of hull weight is absorbed by framing hence this is a fertile field for weight reductions. There is little justification for materially reducing longitudinal framing since each piece contributes to the

longitudinal strength of the vessel. However, such material can be gainfully re-distributed away from the neutral axis and transformed into items such as hull and deck planking. Transverse frames are in an entirely different category and should be proportioned as lightly as possible to do their job of holding the hull in shape between bulkheads. To remove such members as keelson, sister-keelson, rider-keelson, floors, etc., necessity for clamping frames at the keel must be eliminated. Obviously, then the frame must be continuous across the keel. Furthermore, in order to preserve the strength thus gained, the frame must be made continuous from head to head.

A second field for weight reduction is the heavy ceiling of conventional construction. Longitudinal material utilized on the inboard side of the frame can be more advantageously employed strengthwise in the outboard side in the form of planking. Removal of this ceiling immediately poses a problem of substantial magnitude. Without clamping action afforded by planking and ceiling, conventional futtock frame construction cannot be safely employed. Obviously a solid frame is the solution to the problem, but unfortunately very few trees grow in the shape of a midship frame for a large vessel. It is true that certain types of trees are cooperative in that they

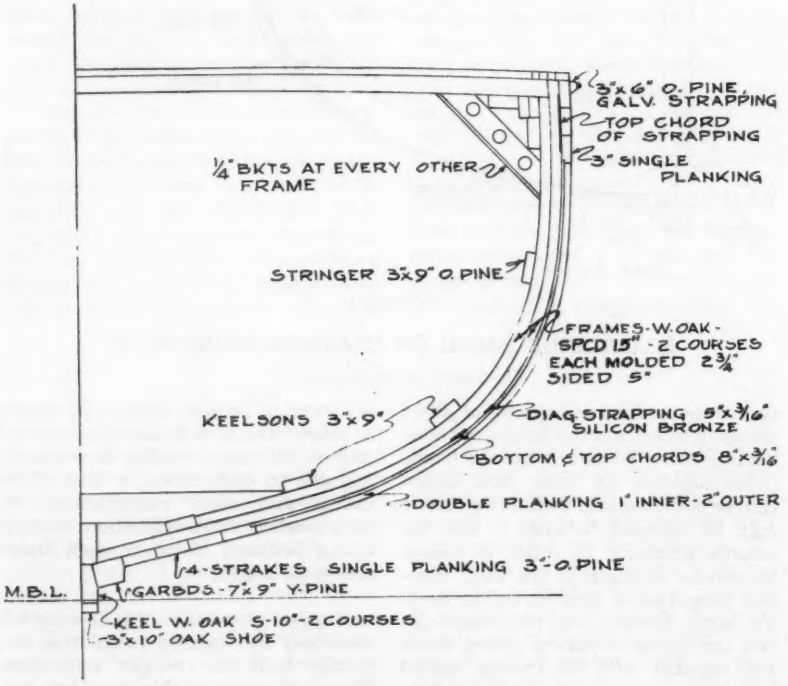
3"x6" O. PINE, GALV. STRAPPING
TOP CHORD OF STRAPPING
3" SINGLE PLANKING
1/4" BKTS AT EVERY OTHER FRAME
STRINGER 3"x9" O. PINE
FRAMES-W. OAK-SPCD 15" - 2 COURSES EACH MOLDED 2 3/4" SIDED 5"
KEELSONS 3"x9"
DIAG STRAPPING 5"x3/16" SILICON BRONZE
BOTTOM & TOP CHORDS 8"x3/16"
DOUBLE PLANKING 1" INNER-2" OUTER
4-STRAKES SINGLE PLANKING 3"-O. PINE
M.B.L.
GARBDS-7"x9" Y. PINE
KEEL W. OAK 5-10"-2 COURSES
-3"x10" OAK SHOE

FIGURE 2

WORLD WAR II MINESWEEPER YMS CLASS

lend themselves to being reshaped by bending but in large sizes and long lengths they come few and far between. The only other solution is to manufacture a solid piece of lumber to run continuously from head to head and of the correct shape to keep the hull fair.

WORLD WAR II YMS

One of the most pronounced advances in wood ship design suitable for production in large numbers was the YMS of early World War II design illustrated in Figure 2. The scope of this change of concept of design can be appreciated by comparing the constructions illustrated in Figures 1 and 2. Two major departures from conventional construction were complimentary, in that elimination of the piecemeal futtock frame construction removed the necessity for clamping action afforded by a ceiling and conversely, elimination of ceiling construction necessitated built-in continuity of frame. This continuity in the case of the frame was achieved by means of steam bending of unusually long pieces of oak. The elimination of the ceiling also removed in one step a major curse of wood ship construction, namely the poorly ventilated, decay-inducing air space between ceiling and planking. Further innovations in this design were the substitution of light struts for massive knees at the junction of shell frame and deck beam, severe reduction in the number of timbers at the keel line, substitution of light floor construction, and the reduction of size and number of timbers at the intersection of shell and deck. Furthermore, scantlings in general were made considerably lighter than would be customarily required by classification rules. Unquestionably it took courage and vision to upset precedent and convention to such extent especially in the case of a vessel subject to such rigorous duty as a mine-sweeper. The excellence of this design has been born out through the years by fine service performance on the part of nearly five hundred ships of the class. Because of its excellent showing, it has been selected as the prototype for the new AMS design now in production.

POSTWAR MINESWEEPER DESIGN

In the early stages of the recent minesweeper program the Bureau of Ships was faced with the necessity of designing a strong, non-magnetic ship to handle heavy minesweeping gear. Having taken one substantial step in the development and refining of wood ship construction, the Bureau of Ships was ready to incorporate new techniques and theories in the process of development. These steps comprised something old and something new in the wedding of modern wood techniques to the oldest construction material known to man. The "old" came from the wealth of knowledge and experience gathered during the days when wood shipbuilding was in its prime; the "new" came from the modern revolution in wood manufacture and assembly. The midship section of the AM421 Class illustrated in Figure 3 is the end result of many months of tests, research, and consultation with experienced wood technologists, naval architects, and shipbuilders.

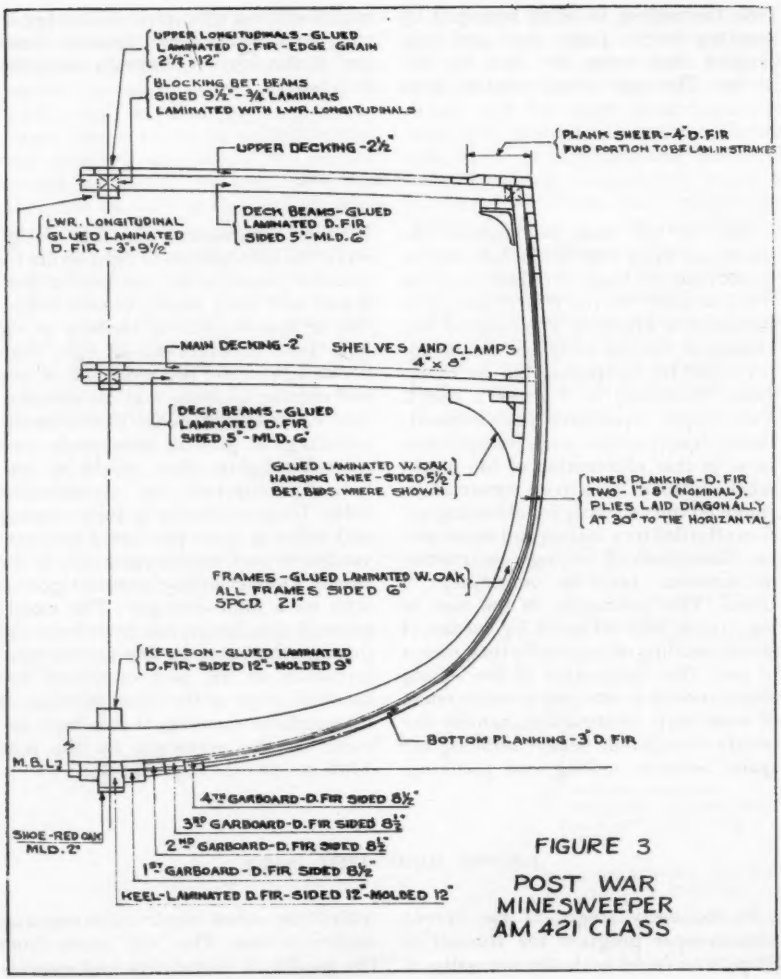
UPPER LONGITUDINALS - GLUED LAMINATED D. FIR - EDGE GRAIN 2½" x 12"
BLOCKING BET. BEAMS SIDED 9½" - ¾" LAMINARS LAMINATED WITH LWR. LONGITUDINALS
PLANK SHEER - 4" D. FIR FWD PORTION TO BE LAMIN STRAKES
UPPER DECKING - 2½"
LWR. LONGITUDINAL GLUED LAMINATED D. FIR - 3" x 9½"
DECK BEAMS - GLUED LAMINATED D. FIR SIDED 5" - MLD. 6"
MAIN DECKING - 2"
SHELVES AND CLAMPS 4" x 8"
DECK BEAMS - GLUED LAMINATED D. FIR SIDED 5" - MLD. 6"
GLUED LAMINATED W. OAK HANGING KNEE - SIDED 5½" BET. BEDS WHERE SHOWN
INNER PLANKING - D. FIR TWO - 1" x 8" (NOMINAL). PLIES LAID DIAGONALLY AT 30° TO THE HORIZANTAL
FRAMES - GLUED LAMINATED W. OAK ALL FRAMES SIDED 6" SPCD. 21"
KEELSON - GLUED LAMINATED D. FIR - SIDED 12" - MOLDED 9"
BOTTOM PLANKING - 3" D. FIR
M. B. L. W.
4TH GARBOARD - D. FIR SIDED 8½"
3RD GARBOARD - D. FIR SIDED 8½"
2ND GARBOARD - D. FIR SIDED 8½"
1ST GARBOARD - D. FIR SIDED 8½"
SHOE - RED OAK MLD. 2"
KEEL - LAMINATED D. FIR - SIDED 12" - MOLDED 12"

FIGURE 3

POST WAR MINESWEEPER AM 421 CLASS

BASIC CONCEPTS AND CRITERIA

The aforementioned background of history and reasoning led to a basic concept of a new minesweeper design combining new wood manufacturing techniques with tried and tested construction systems. Its foundation was conceived as made up entirely of members manufactured by the technique of wood laminating. Hull stiffness and lightness was gained in the form of double diagonal planking already discussed. Bulkhead strength and stiffness

was obtained in the same way. Fastenings were made as small and as numerous as practical in order to spread load transfer over a reasonable area of wood. Deck girders were designed as I-beams, fully laminated where possible, otherwise connected together by bolts and split ring connectors. All structural members were calculated using assumed loads as severe as could be reasonably contemplated. Allowable stresses were in general, based upon the strength of clear, sound, dry wood, a condition almost impossible to find in large solid timbers. The end result as illustrated in Figure 3 is less than 50 percent the weight of the same basic ship scantlinged in traditional manner.

It became necessary early in the design of the 165 foot minesweeper to establish a reasonable criteria of design stresses for laminated timbers. Tables of design stresses for solid timbers were much in evidence but had little practical value for laminated members. Defects such as knots, shake, cross-grain, etc., which modify the strength of solid timbers do not affect laminates to the same degree since their effect is limited to one ply. On the other hand strength data for clear laboratory specimens cannot be safely used for large structural items because of the ever present variability of structure and strength falling within a single stick of lumber. In order to arrive at an orderly set of design data, Timber Engineering Company personnel were called upon for consultation. At first it was thought that a starting point could be data as derived from clear laboratory specimens, these values to be modified by imposing suitable safety factors for various conditions of loading. It was soon apparent that due to the variability of wood it would be necessary to include an experience factor. The Bureau of Ships publication "Wood: A Manual for Its Use in Wooden Vessels" (2) includes in table 5-2 a list of stresses to be used in design and based upon the strength of clear solid timbers. The design stresses in this table were arrived at by including an experience factor. Therefore it appeared logical to start with the stresses set forth in this table and suitably modify them for use for laminated structure.

A laminated member is of necessity at a relatively low moisture content since wood in order to be successfully glued must be at a moisture content of 15 per cent or less. A solid beam on the other hand is very difficult to dry and will be used at a moisture content approaching that of green timber. Since table 5-2 was predicated on large timbers of high moisture content, and since dry wood has stronger properties, an increase of table 5-2 values could be safely assumed for laminated beams. A conservative figure for this increase of strength was determined as 25 per cent. Furthermore, laminating reorients defects and reduces the effect of variability normally found in a single stick of wood. This reduction in variability of strength was good for another 20 per cent increase in allowable stress.

Other increases in allowable stress were based upon wood's natural increase in resistance to damage under loads of short duration. For loading of limited duration such as under conditions of dry docking or internal flooding, allowable stresses were increased 25 per cent. For loading of short duration such as caused by waves, allowable stresses were increased 75 per cent. A shock load such as caused by underwater explosion or gun reaction allowed an increase of stress of 100 per cent. These percentages are cumulative. Thus a laminated Douglas fir deck beam would be designed to an increase of 120 per cent ($20 + 25 + 75$) or 4400 p.s.i. instead of the 2000 p.s.i. of table 5-2 of the Manual.

A further increase of allowable load was determined as feasible in the case of definitely known loads such as a hydrostatic head upon bulkheads. This increase was selected as 50 per cent and was in effect, a reduction of safety factor based upon known loading conditions. Since table 5-2 stresses included a safety factor of about 2-¼ for long time loading, or 4 for short duration loading, it was reasonable to reduce these factors by 50 per cent where the necessity for safety factor was not critical.

SKIN CONSTRUCTION

The lessons taught by ships of an active era of wood ship design and the experience gained from consultation with numerous designers and builders of long experience, resulted in the decision to design the hull of the 165-foot minesweeper as triple planked with two courses of ¾ inch planking laid double diagonally at 30 degrees to the fore and aft, and a single course of 2-½ inch planking laid fore and aft. This system achieves lightness by providing great hull strength in torsion and shear; disposes the unidirectional properties of wood in three directions thereby making a system of construction of more homogenous nature; provides more efficient longitudinal strength in bending by virtue of increased shear rigidity; and eliminates metal strapping as shear carrying members. The elimination of metal strapping is of definite advantage. The modulus of elasticity of metal is several times as great as that of wood. Therefore, strapping tends to bear a greater proportion of load than the immediately adjacent wood. Since the load originates in a relatively large area of wood in the vicinity of the strapping, all load must be transferred to the strapping over the smaller area afforded by the fastenings. Because of this, metal members tend to impose severe local loads on their connections to wood planking or frames and to the wood in the region of these fastenings.

FRAME LAMINATING

The decision to use laminated framing extensively posed several serious problems. First in order of importance was selection of fabricators of the frames. As has been mentioned the frame would have to be manufactured as one piece from frame head to frame head. The hull dimensions were such that the majority of frames would be too large to ship by means other than water or special truck. In the event of an accelerated building program this would be impractical as limiting the fabricator to regions of navigable waters or require setting up complicated and cumbersome highway routes.

The obvious solution to the transportation problem was to depend upon the professional laminator only when he was convenient to a shipyard. In the majority of cases the yard would not have a ready source of supply and would have to manufacture the frame in its own plant. Thus, the whole success of the program from the very outset depended upon the ability of a shipyard, generally ill-equipped for large scale laminating, to enter successfully into a new field. The question was further complicated by the selection of oak as the preferred material for the frames, necessitating

relatively high curing temperatures and close humidity control.

The laminating of large wood structures is a specialized process generally requiring machinery foreign to the average shipyard. Acceptable tolerances for board thickness and surface preparation are low; gluing and assembly necessitate special skills and time control; pressure requirements in clamped condition necessitate specialized equipment; and curing of the assembly, one of the most critical aspects of the process, requires close temperature and humidity control. The manufacturers of laminated structures have, through the years, evolved and equipped their plants with specialized surfacers, glue spreaders, clamps, and kilns. To equip each yard with this expensive equipment would be impractical.

Since the success of the program depended upon the ability of the shipyards to manufacture their own frames, contracts were let with Luders Construction Co. to build a full scale U-shaped frame of oak and with the Wheeler Shipyard Co. to build a full-scale U-shaped frame of Douglas fir. Each company developed their own techniques and solved numerous problems in able and workmanlike manner. Much credit for the initial success is due the various organizations and people who acted in an advisory capacity to both companies. The personnel of the laboratory of Timber Engineering Co., the Forest Product Division of the Department of Agriculture, Messrs. Kuenzel and Cranch of the Wood Products Branch and Lts. Noyes and Latase of the Raw and Basic Materials Branch of the Bureau of Ships gave freely of their time and experience to help insure success of the project.

Upon completion of the manufacture of the two frames, each was cut into test sections and shipped to the laboratory of Timber Engineering Co. for strength and delamination tests. All sections yielded strengths substantially equal to values expected of small clear laboratory specimens of the species. This in itself was highly gratifying since comparable results could not be expected of solid high-grade timbers due to the unavoidable defects and variability to be found in large timbers. In addition, the block shear and delamination tests met all specified requirements and established without question that the techniques used by the shipyards were practical and resulted in strong and durable members. The wood shipbuilding industry has taken a major step forward in the development of new construction techniques due to the able pioneering of these two companies and their advisors.

The tests proved conclusively that oak frames could be manufactured entirely within the plant of the shipyard. That hurdle having been overcome, it was obvious that other members of more simple construction would not present formidable problems to the yards. In addition, the strength tests made on sections of these frames proved the excellence of laminated construction for large beams. This led to the final decision to use timbers in as long lengths as could be handled by the yard. The backbone of the vessel consists of a one-piece stem, a one-piece 12 inch by 12 inch keel over 100 feet long, a one-piece 12 inch by 9 inch keelson also over 100 feet long, and a one-piece combination horn timber, keel and deadwood. All deck beams, stringers, girders, wood knees, large foundations and filler blocks are of one-piece laminated construction. The only exception is a few deck girders which were made up as a lower laminated one-piece flange with shear blocks secured to it with adhesive and placed to fit between deck beams, the

top flange being a one-piece laminate forming a portion of the deck planking and being fastened to the lower assembly by bolts and split ring connectors. Later in the building program some yards requested permission to attach the upper flange by adhesive in place of bolts.

RESEARCH AND DEVELOPMENT

Research pursued in conjunction with the design was directed toward investigation of specific problems (3). As has been mentioned, fabrication and test of full-size laminated frames was of paramount importance. These frames were so cut that one such test section consisted of the bottom portion, a second test section encompassed that portion at the turn of the bilge and a third section included the upper portion of the frames. It is interesting to note that despite the rather severe curvature at the turn of the bilge, this section showed a modulus of rupture of 80 to 90 per cent that of the straight sections. The average modulus of rupture for all three sections was 9500 p.s.i. for oak (13900 for small clear laboratory specimens) and 9000 p.s.i. for Douglas fir (11700 for laboratory specimens).

In order to evaluate or compare the relative strength of laminated and solid beams one bending test specimen was made up of laminated oak beam and a solid oak beam. The latter was carefully selected for straight grain and minimum number of defects. The laminated beam was tested at a moisture content of 7.7 per cent and the solid beam at a moisture content of 34 per cent. These moisture contents are representative of those normally expected of the two types of beams, the solid having been air seasoned for at least one year prior to test. The results showed a modulus of rupture of 13200 for the laminated beam and 8400 p.s.i. for the solid.

Because little data on the strength of various types of knee assemblies were available five types of assemblies were developed and tested. The best from the standpoint of both ultimate strength and proportional limit was a laminated bosom knee bolted to the interior faces of the frame and beam. There followed, in order of merit curved laminated cheek or gusset pieces glued and bolted to both side faces of the frame and beam; a cast silicon bronze bosom knee bolted to the interior faces; silicon bronze channel-shaped struts bolted to both side faces, and of least merit, flanged silicon bronze cheek or gusset plates bolted to the side faces of frame and beam.

A series of direct and lateral withdrawal tests of six inch bronze lag screws in oak and Douglas fir yielded the information that the holding power in oak (3 inch screw penetration) was equal to or greater than the strength of the fastening. The holding power in oak under conditions of direct withdrawal was 60 per cent better than in Douglas fir and was 40 per cent better for lateral withdrawal. Tests were also conducted to determine the holding power of the head in 2-½ inch Douglas fir planking. It was found that a 1-¼ inch washer under the head increased the holding power by 60 per cent. Furthermore the holding power of the head plus washer in the planking was 60 per cent of the holding power of the screw in oak but only slightly better than the holding power of the screw in Douglas fir.

Further experimentation and tests resulted in acceptance of such items as laminated oak bending stock (4) (for AMS construction), end scarfed and glued planking (5), and preservative

treated glue-laminated woods (6). The laminated oak bending stock alone has cured many procurement headaches in the AMS program. Wood which in solid form is unsuitable for steam bending can be cut into strips, shuffled together and subsequently glue laminated into bending stock equal to or superior to solid stock of bending grade. Preservative treated laminating stock opens the door to complete decay resistance for large timbers. End scarfed and glued planking means utilization of short lengths to achieve planks of length only limited by handling facilities.

PRESERVATIVE AND PROTECTION

Strength and durability are the two most desirable qualities in a structural material. Wood excels in its ability to carry load but it is generally deficient in decay resistance, especially in marine environments. This need not be a deterrent to its use however, for the natural decay resistance of wood, great or little as it may be, can be supplemented by the introduction of decay inhibiting chemicals into its cellular structure. In order to be fully effective the wood should be completely penetrated with the preservative, which for most species necessitates introduction of the solution by some pressure means. This in turn requires specialized equipment large enough to handle the largest timbers to be used. A much inferior way to partially preserve is to treat the surface to the maximum depth possible by means of surface application by brush, spray, or dip.

One of the oldest, most effective preservatives is creosote oil. Millions of board feet of utility poles, fence post, railroad ties, foundation timbers, etc., have been successfully treated with the material and it continues to be the number one preservative. For several reasons creosote oil is unsuitable for preservation of ship timbers. It should not be used on interior portions of living spaces because of its objectionable odor; it cannot be used on timbers whose surfaces are to be painted, since standard oil paints will not readily adhere; its weight is excessive in comparison with other preservatives of substantially equal preservation qualities. Because of these limitations creosote oil was eliminated as a preservative for the minesweepers and instead, solutions containing copper or arsenic salts were used.

The minimum treatment specified was a heavy brush coat on all surfaces after all shaping had been done. Practical difficulties limit the use of pressure preservative treatment to relatively small boards. A cell structure such as in white oak or dense Douglas fir resists the penetration of the preservative to such extent that under the best of conditions protection is limited to less than an inch depth. Therefore, large timbers would not be completely protected even if they could be pressure treated. Another practical deterrent to pressure treating of large timbers is the cost and labor of handling. The item to be treated must first be fabricated in the builders' yards, all rough cutting and shaping completed, and then the item shipped to a treating plant. Furthermore, the cutting and shaping of the timbers must be to as near the finished dimension as possible to reduce the amount of treated wood necessarily cut away in the final finishings to shape. This practically necessitates fitting the timber into the vessels and then removing it for shipment and treatment. This obviously is an impractical way to build wooden vessels.

Since pressure preservative treatment can be utilized to fully protect thin timbers, it was specified for all three-quarter inch stock including that to be protected against marine borers, and for all plywood. Thus the diagonal planking, hull sheathing, bulkhead planking and all plywood was ordered by the shipyard in treated condition. All other members were dip, or brush treated, the former being employed where possible. All cut and bored surfaces were liberally brushed or swabbed with preservative. This treatment, though incomplete from the standpoint of full preservation, should be of great benefit in prolonging the life of these vessels. Time only will be the measure of the success of the treating program.

THE FUTURE

The new designs of the minesweeper program, although a significant advancement over anything of similar magnitude in the past century, are only a step in the possible progress of wood ship design. It is obvious that further refinements of wood structures are possible and probable. Development of new technique for fastening, manufacture, and preserving of structural members will improve strength and reduce weight to the point where wood is in direct competition with steel. It is now a fact that most woods can be fully preservative treated in the form of small pieces and then glued together to form structures of complex shapes and large dimensions. Mechanical connectors have been developed that effectively enable a joint to transmit the load capability of the joined members. Vision and ingenuity will devise structural systems more suited to the properties of wood. Glue laminating shows great promise in enabling selective combinations of wood such that the strength properties of each species is exploited to its fullest. Naval architects have an excellent construction material at their disposal and an introduction to efficient ways of using it. If they accept the challenge presented to them, eliminate inhibitions and outmoded structural concepts, design with imagination and vision, this "new" material will yield them many successful and advanced ship structures.

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"CONTRACTING" IS EASY

CAPTAIN R. E. W. HARRISON, USNR.

THE AUTHOR

was born in Manchester, England, in 1893. Educated Manchester College of Technology. With Royal Engineers, British Army 1914-1919, Egypt, Gallipoli, Sinai, France, Belgium, Industrial Engineering experience includes special apprenticeship and supervisory positions with Churchill Machine Tool Company, England, in the building, design and engineering selling of precision grinding machinery; in 1926 as Director of Engineering, Cincinnati Grinders, Cincinnati Milling Machine Company; 1934 Chief, Machinery Division, U. S. Department of Commerce; 1935 Vice-President Chambersburg Engineering Company; in War II, on staff of Assistant Secretary U.S. Navy, and later as Special Assistant to the Under-Secrtary, Registered Mechanical Engineer in Ohio, New York, Pennsylvania, Maryland and District of Columbia. Fellow ASME and Royal Society of Arts; Member other Engineering Societies in USA and Europe. At present engaged in Engineering and Management Consulting, Washington, D. C.

THE LAW

The man says—"there shall be at least three bids and the contract must go to the lowest *reliable* bidder." Why then, so much blood and sweat and so many tears? Usually, to secure these bids is easy, if the specifications for the work to be contracted, are reasonably clear and complete, which means if the contracting agent or buyer is reasonably hard boiled in demanding and getting clean cut specifications from those whose job it is to provide them.

The law relating to contracts is not too difficult to understand—there are very few words in the law, as written, which any normally intelligent high school graduate cannot understand and interpret into action. However, it is a must that the buyer should be quite familiar with the law, and this means he must read it, study it, and practice it at all times.

THE ETHICS

There are, of course, some ethics applicable to the business, and these can present some difficulty to the uninitiated,—good buying ethics complement the law, in fact, facilitate its application, and if our prospective

buyer can persuade himself that he might be a bit weak in this area, then he should get himself thoroughly informed by seeking guidance and advice from his experienced friends and the copious literature which has been published on the subject.

Ethical procedures are mandatory, otherwise the list of prospective bidders has a habit of shrinking, until those who are left, are of the type who can subscribe to doubtfully ethical procedures; the result: negotiations are pretty much of a rat race, in which the winner is most often the loser in the end.

Needless to say, the principals at interest in the case under review, generally concede that complete honesty in the ethical field is desirable, if for no other reason than that it pays off all along the line and particularly at the end.

THE PROBLEM

In the simplest terms—which bidder gets the contract? This is where the first encounter with blood, sweat, and tears usually takes place. Why? For no other reason than that the buyer has failed to systematize his attack on the problem and ends up with a decision, which if right is only so, by the grace of God, and if wrong, the result haunts his working hours with anxieties, and destroys his sleep with visions of unemployment—or jail. So—seeking the nearest thing to a normal life, what must the buyer do to pick the shell with the pea underneath? It is not too difficult.

THE PREFERRED SOLUTION

Every mechanism—every problem—every situation is inevitably but the sum of its parts and the way to evaluate the problem is to break it down into its parts—analyze and evaluate them individually and in their relation to the whole, reassemble the parts into the workable whole; check the end results for accuracy—add up the scores and lay the end results on the line, as representing best carefully considered judgment on the case in hand.

Time with which to follow this procedure?—Yes, it is always there if one seeks it. Time is always relative—the incompetent never have any to spare—they are always so busy catching up with the parade—however, in the buying or contracting business, time to analyze, should always be rigidly budgeted for, otherwise the buyer may end up with an unexpected surplus of it—unemployed or worse; in the hoosegow.

What is that which is sought? Surely it is the procurement of something which honestly meets the specifications laid down in the contract, delivered in the time stipulated and agreed to by the contractor. All at a price which is the lowest obtainable in the market existing at the time of the making of the contract.

In buying on behalf of a government there can be times when politics—economic pressures dictate the insertion of some special elements into the prebuying analysis of bidders and their products. It is of the utmost importance, however, that the specifications for the product be absolutely precise and where applicable with clearly stated tolerances. The minimum re-

quirements in respect to the reliability of bidders also must be enforced. All of this without any reference whatsoever to the varying winds of politics—economic pressures or personal likes and dislikes.

Given reliable bidders offering a product which is acceptable within the advertised specification, there can, as occasion may direct, be added to the bid evaluation analysis, columns and weighting factors in a secondary analysis designed to accommodate "distressed areas," in areas which it is "militarily desirable to build up" as alternative sources of supply or perhaps a need in this instance to consider "small business."

The recommended basis of analysis are shown in Tables I and II. These are examples only, designed to demonstrate a principle.

TABLE I

1ST BID ANALYSIS (PEACE TIME). NO ABNORMAL CONDITIONS.

	Price	Delivery Acceptability	Contractor's Facilities	Contractor's Record-Delivery Performance	Local Labor Supply and Correctability	Contractor's Labor Relations—i.e. Continuity of Operation	Contractor's Adequacy Of Financial Resources	% Of Offered Adherance To Contract Specifications	Management Experience With This Product	Contractor's Ability To Secure Materials	Contractors' Score
Factor Weight %	15	10	25	5	5	5	20	5	5	5	100%
Bidder A	15	10	15	0	5	0	10	0	0	5	60
Bidder B	0	10	25	5	5	5	20	5	5	5	85
Bidder C	10	5	10	5	5	5	10	5	5	5	65

Bidder A—low bidder
Bidder B—high bidder
Bidder C—medium bidder

RESULT OF 1ST BID ANALYSIS

1st choice for contract award.....Bidder B with 85 points
2nd choice for contract award.....Bidder C with 65 points
3rd choice for contract award.....Bidder A with 60 points

TABLE II

2ND ANALYSIS OF BIDS (SPECIAL CASES)

Taking into account special conditions, "Distressed Area," "Military desirability of area," "Small business"

	Distressed Area	Military Desirability of Area	Small Business	Total
Relative Weights	Allocated Weight 35%	Allocated Weight 40%	Allocated Weight 25%	100%
A 60	35	none	25	120 Score
B 85	none	yes 40	Borderline 15	140 Score
C 65	Partial 20	none	25	110 Score

RESULT OF 2ND BID ANALYSIS (SPECIAL CONDITIONS)

1st choice for contract award.....Bidder (B) with 140 points
2nd choice for contract award.....Bidder (A) with 120 points
3rd choice for contract award.....Bidder (C) with 110 points

CONDITIONS—SPECIAL AND OTHERWISE

From the foregoing, it can be logically deduced that the injection of special conditions, such as distress areas, small business fostering, and military desirability of procurement in a certain area, need not and should not be permitted to break down a system of contractor selection which has been designed for the protection of the buyer's (in this case the government's) interests.

Judgment of the highest quality is required in evaluating the special and additional factors of "distress areas," "small business fostering," and "military desirability of build up in certain area."

The importance of "distress" and the weighting which it justly rates can be easily analysed when the *facts* and relative *facts* are made known. Likewise, the same procedure can be made to produce a decision in the case of "military desirability of area."

All that is essential is a flat footed bearing down on the need for facts, as distinct from opinions and just plain political pressures.

When the point at issue is the fostering of small, as distinct from big business, the decisions to be made are somewhat prone to be confused.

Almost any government buyer will testify that it is easier and cheaper to do business with the larger and better established producers, and that the advantage persists all the way up and down the line from preliminary negotiation to delivery of the finished product and subsequent service in the field.

Small producers; "makee learns" in service parlence, simply lack the experience and resources which make for satisfactory handling of a great many military contracts, at least on the first go around.

This author, however, is convinced that there exists a table of evaluation factors which can be logically and fairly applied to "small business" and other special conditions, contractors selection. This basis of selection is outlined in Tables II and III.

TABLE III

Category	Examples	General Nature
A	Lead pencils and other office supples. Primary training equipment	Equipment for use on the home front
B	Building materials and plumbing	Equipment for use at intermediate stations between home and battle areas
C	Transportation equipment Aircraft Rifles All ammunitions All communication equipment Food Cannon Special weapons Aircraft carriers and other combatant ships	Equipment for use in battle and all forward areas

DISCUSSION OF TABLE III

Category A equipment contracts offer a fertile field for the fostering of new manufacturers; even in war time there can be much economic merit in keeping these small businesses in existence. Sight should never be lost of the fact that small businesses are the seed corn from which big concerns grow. Where such desirable small companies cannot make the grade unaided, the ground can still be cultivated by making sub-contracting mandatory when handing a contract to a large supplier.

Category B equipment is more combat sensitive, and fewer liberties or hazards are permissable when arranging for its supply. Nevertheless, sound judgment aided by systematic analysis will still show the way to spread the production load without making the big concerns bigger—or starving the smaller concerns to economic death.

Category C equipments are war sensitive throughout and no liberties or avoidable hazards are permissable. Only contractors of proven ability and absolute integrity should be dealt with.

INSPECTION

It has been many times asserted that the government inspection system adequately safeguards all against acceptance of faulty or even doubtfully reliable equipment. The value of this statement hinges on definition of the word "adequate." Judgment as to what is adequate rests in the long run with the night fighting aviator and the soldier on patrol in enemy territory. The plane engine which fails, or the grenade which does not explode are the eventual testing areas—but the facts frequently become apparent too late to permit correction at source. War is a frightfully bloody business, you know.

Experience in the field has proven beyond shadow of doubt that in addition to the safeguarding inspection of a manufacturer's products, there must be a sense and practice of absolute integrity on the part of the manufacturer.

Poetic justice can produce some queer quirks. In the United States where all available males can be called on to serve, it could be that it is the manufacturer's own dearly beloved son who pilots the plane with the failing engine, or the man on patrol who tosses the grenade with the faulty fuse.

TECHNIQUE OF BID ANALYSIS

Price

The high price, however, reasonable scores zero. The low price full marks, and the intermediates are rated in strict proportion between high and low.

Delivery

Delivery is dealt with in the same way. The contractor offering the shortest (reliable) delivery gets top score—the one offering the longest delivery—scores a zero. Intermediates are rated pro rata.

Contractors Facilities

These must be made the subject of an on-site inspection by a neutral, thoroughly and professionally competent observer. The completely adequate (for the work proposed) plant gets the high mark and the poorest plant the low mark. Others are very carefully rated in between.

Contractor's Record

Exactly as disclosed by a search into the veracity of the individual who made the previous promises on delivery performance.

The contractor who systematically anticipates his promised delivery dates gets the top score; the inveterate optimist who fails—or the prevaricator gets a big 0—others in between.

Local Labor Supply

This situation requires on site verification by a competent observer—it is not difficult for such a person to get at the facts as there are many independent and honest sources of information.

It is useless to give a contract to a man who lacks man power—no matter what his bid price and delivery may be. Score accordingly.

Labor Continuity

Generally a matter of local record, but it needs on-site verification.

Financial Resources

The contractor's last financial statement plus a current D&B report are usually adequate — however, a letter (in specific terms) from the contractor's banker is a big help.

The man who can take on the job without borrowing working capital gets the high mark—the chronic borrower—always in trouble with his bank is low man on this totem pole—others at intermediate stations.

Adherence to Specs

Usually this is easy to evaluate but the neophyte buyer must beware of the phrase—"or equal"—Who to Judge? Only an expert and that is practically never the actual buyer.

To secure integrity at this point the "or equal" bid must be made the subject of a detailed technical analysis by an expert.

Divergencies from the specs strike at the very roots of the transaction and they should be avoided like the plague. The bidder who says "no exceptions" and means it gets the high mark—the "or equal" operator gets a place on the scale as dictated by an expert on the equipment under discussion.

Management Experience with this Project

This is a matter of record—D&B can help but a frank and full statement (signed) by the prospective contractor is of most value. Some checking by the buyer or his agent is however in order. Naturally the most experienced bidder gets the top score—others as rated.

Raw Materials (Ability to Secure)

A good trade rating (credit), good access and good communications all add up to reliability in this area—another factor is the accumulated experience of the contractor's buyer in the procurement of this type of material.

A look at this individual's ability to schedule the deliveries of his purchased material is another indication of competence which will bear looking into.

CONCLUSIONS

This article is not by any means intended as a primer of ten easy lessons on how to buy boats, peanuts or machinery. It is essentially an exposition of principles which have paid off in a practical way during the buying of many millions of dollars worth of a wide assortment of products.

Those who spend public money must, of necessity, always be ready, willing and able to answer reasonable public questions. The same necessity applies equally, when we spend company money as a private or government contractor.

When we must buy under war time conditions it often happens that price fades to relative insignificance—at other times price rates a much larger proportion of the allowable points.

During war—delivery on scheduled time is all important—hence scheduling on a truly practical basis is a must. We all know the ape who must have everything yesterday; his contribution to general confusion is paramount. Briefly, this particular form of menace comes close to sabotage.

Percentages used in the tabulations as weighting factors vary with almost every purchase and every period of time. The selection of these percentage weightings is the duty of management and cannot be dodged.

The master production schedule is the final authority in setting the weight to be attached to delivery—it also is a management responsibility.

Injection of too much extra—legal ledgerdemain into contracting decisions has bred in many contracting departments a false sense of dependence on the lawyers.

That the lawyers have been willing in the past to assume the job of making commercial decisions for disorganized purchasing departments is ample proof of their capacity for work. That the big boss has been willing to let the lawyers do the work of the Purchasing Agent is but another demonstration of *laissez faire* at work.

In those purchasing departments in which it has been this author's good fortune to supervise systematic analysis of bids the result has been sound business and sound sleep at night. In those cases where chaos reigned, the first analysis soon disclosed those who seemed to profit by confusion, and after that phase has been dealt with, the rest is easy—spinal reinforcement can be painless if applied with the salve of logic.

NEW METALS FOR NUCLEAR TECHNOLOGY

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The primary form of energy in a nuclear reactor is the kinetic energy of the fragments resulting from fission. Since no means has yet been developed for utilizing these high energy particles directly, their energy is degraded to ordinary heat energy by collisions with matter in the reactor core. Power reactors may thus be regarded as basically similar to conventional boilers, with the exception that temperatures considerably in excess of those available from the oxidation of chemical fuels are theoretically possible. The high thermodynamic efficiency thus implied cannot be realized practically, however, since all of the materials limitations in other heat engines are present plus a few that are unique to power reactors.

The major new requirement with respect to engineering properties is resistance to radiation damage. Zinn and others have described the drastic changes that may occur when uranium is exposed to nuclear radiation. All metals suffer, to a greater or lesser degree, changes in dimensions, thermal conductivity, strength, and other important properties when used in a reactor.

Fortunately, just as the usual engineering properties of metals may be altered and optimum combinations of properties obtained by conventional metallurgical techniques of alloying, heat treatment, and mechanical working, so also may the problem of radiation damage be attacked. The primary difficulty of the reactor metallurgist is not the unusual combination of engineering properties required for a variety of applications—strength, ductility, corrosion resistance, freedom from excessive radiation damage—but rather the limited choice of metals available from which to develop a solution. This limited choice arises from the fact that the metals used in the reactor must generally also serve a nuclear function, or if they serve no nuclear function must at least satisfy certain nuclear restrictions. These restrictions are most severe in the case of thermal reactors and most of the discussion assumes such a design.

There are five convenient functional categories into which metals used for the reactor core can be divided. These are: structural materials, moderator materials, control materials, fuel materials, and source materials.

Structural Materials. Based on these categories, structural materials serve no nuclear function. However, for neutron economy—which in the future may well also be dollar economy—the structural materials must have a low neutron capture cross section. That this is indeed a restriction may be realized from the fact that none of the major constituents of common corrosion resistant and high temperature alloys—iron, nickel, chromium, cobalt, tungsten, molybdenum, titanium—have thermal cross sections sufficiently low for attractive neutron economy. It is to be noted that intermediate and fast reactors provide rather more leeway in this respect and materials like stainless steel may often be used. Of the low cross section metals, only beryllium, zirconium, magnesium, and aluminum have potentially useful structural properties. Because of relatively low melting point, poor mechanical properties at only slightly elevated temperatures, and questionable corrosion resistance in desirable heat transfer media, magnesium and aluminum appear unattractive. It is thus not surprising that extensive development programs have been carried out on zirconium and beryllium.

Moderator Materials. Moderator materials serve the nuclear function of slowing down neutrons from the very high energies at which they are born in fission to thermal energies. They must have low atomic weight and low cross section. The only metal satisfying these requirements is beryllium and thus it attracts a twofold interest. It is to be noted that nonmetals such as hydrogen, deuterium, and graphite are often used as moderators.

Control Materials. Control materials serve the nuclear function of absorbing neutrons in a controlled manner to permit adjustment of reactivity. By inserting or withdrawing such materials, the reactor can be shut down, started up, or its power level changed. Materials having very high absorption cross sections are ordinarily used for control purposes. Although most metals have cross sections too high for efficient use as structural materials, only a few have cross sections sufficiently high for efficient use as control materials. Some metals that have been proposed are cadmium, boron, certain rare earths, gold, and hafnium. Cadmium has a rather low melting point. Boron has a high melting point, good resistance to many corroding media, but is rather brittle. If used for reactor purposes, it is likely that these metals will be minor alloying constituents in a base metal of more suitable engineering properties. The rare earths are quite scarce and expensive and probably have unsuitable engineering behavior. Gold has the obvious disadvantage of cost. Hafnium perhaps provides the best combination of high cross section with desirable engineering properties.

It is interesting to note that there may be a significant difference in the behavior of low cross section structural and high cross section control materials in a high power reactor. As a result of neutron capture, some of the original atoms may be transmuted to a new chemical species, thus producing an alloy of gradually changing composition. Since the number of new atoms formed is directly related to cross section, the control materials will form much more concentrated alloys than the structural materials. Assuming a quite reasonable reactor, one could show that several per cent of mercury would form in a gold control rod, with the possibility of rather un-

desirable consequences. On the other hand some materials simply form other isotopes of the original chemical species and are thus unchanged metallurgically.

Fuel Materials. Fuel materials serve the nuclear purpose of providing fissionable atoms. The most familiar material is uranium-235 which occurs in natural uranium to the extent of 0.7%. A less familiar material is uranium-233 which is formed by neutron bombardment of thorium; to the metallurgist it is indistinguishable from other uranium. Finally, there is plutonium which is formed by neutron bombardment of uranium-238. It is extremely toxic and much care must be exercised to prevent its ingestion in the body. The complications arising from the remote handling usually necessary are considerable, and it has been estimated that the time taken in an experiment involving plutonium may be as much as five to 10 times greater than normal experiments in which such precautions are not necessary. It is clear that fuel materials do not provide the metallurgist much freedom for the development of superior properties. For some applications, small alloying additions of low cross section elements can be considered. In a few cases, the fissionable element may be a small alloying addition to a different base metal and in such cases the metallurgist has an opportunity to exercise ingenuity.

Source Materials. Source materials serve the nuclear purpose of providing atoms which can be transmuted into fissionable material. As mentioned previously, examples are thorium and uranium-238. Again the choice available is severely limited.

In many reactor designs, metals are called upon to satisfy most or all of the functional requirements enumerated above. The number of nuclearly desirable metals in each functional category is, as has been seen, quite limited: zirconium and beryllium for structural purposes; beryllium for moderating purposes; hafnium, boron, and a few others for control purposes; uranium and plutonium as fuels; and uranium and thorium as source materials. It is not always possible—using a preferred metal—to develop treatments or alloys that satisfy the usual material requirements of strength and corrosion resistance, plus the unusual requirement of resistance to radiation damage. In such cases, the engineering expedient of designing around the difficulty can be used or the nuclear requirement can be compromised.

Until recently, these metals were litle more than laboratory curiosities. Therefore, a review of the scientific and technological status of their metallurgy will indicate rather clearly what restrictions they impose on the design of economic power reactors. Understandably, this story cannot be complete, for many of the significant technological problems dealing with specific reactor applications cannot be disclosed.

The metals to be considered are zirconium, beryllium, and uranium.

NO METAL HAS PARALLELED THE ZIRCONIUM ZOOM

Of all the new structural metals which have been developed as a result of atomic energy requirements, none has paralleled the almost explosive expansion of zirconium either in its production, application, or technology. In 1945 the entire United States production of zirconium amounted to only 20

pounds per year. It was made by Foote Mineral, retailed for $300 per pound, and was used almost exclusively for such small scale applications as getters in electronic devices. Starting in 1948, when the AEC began to take an interest in nuclear applications of zirconium, production capacity has increased tremendously and the cost has declined steadily. The AEC has recently contracted with Carborundum Metals for the production of 150,000 pounds of zirconium per year at a cost of less than $15 per pound. The technology of zirconium has experienced a similar development to a point such that, whereas five years ago the metal was a rarity of unknown engineering properties and potentialities, today its technology is further advanced than is that of many other metals know and used for decades.

Zirconium is the eleventh most common element in the earth's crust and is thus more plentiful than metals such as copper, lead, nickel, and zinc. Large workable deposits exist in Florida and equally large reserves have been located in California, Oregon, and Idaho; in addition workable deposits occur in Australia, Brazil, India, Ceylon, and Malaya. The metal is therefore nonstrategic and large reserves are available to the free world.

Two unique properties of zirconium affect its extraction, fabrication, and utilization. The first of these, which will be discussed later, is the marked affinity of zirconium for oxygen and nitrogen, and the stability of the compounds formed by reaction with these gases. The second is the transparency of zirconium for thermal neutrons.

Interest was first aroused in zirconium for nuclear applications in a rather odd way. In 1947, A. R. Kaufmann of Massachusetts Institute of Technology noted a difference of a factor of 10 in published values of the absorption cross section of zirconium. He called this difference to the attention of E. P. Wigner of Oak Ridge, pointing out that the lower value would make zirconium an excellent structural material for thermal reactors while the higher value made it rather unattractive for this application. It was immediately clear that the lower value was the result of a numerical error but the excellent properties of zirconium as predicted by Kaufmann aroused sufficient interest that the original data were reexamined.

HAFNIUM IS ZIRCONIUM CONTAMINANT FOR ATOMIC ENERGY APPLICATIONS

It was found that the specimen used for the measurements contained about 2% hafnium which is a contaminant in practically all zirconium minerals and is not removed by usual metallurgical processing. Since hafnium has an absorption cross section nearly a thousand times larger than that of zirconium, the reported value for cross section of the sample was correspondingly high and the true value for zirconium could be obtained only when the presence of this contamination was taken into account. Therefore, for atomic energy applications it is necessary to separate hafnium from zirconium. The cost of separation has not been disclosed, but it may be inferred from the price of less than $15 per pound quoted previously for zirconium metal that the cost can be no more than a few dollars per pound.

The bulk of the zirconium commercially produced today is made by the Kroll process which was developed at the Albany Oregon Station of the U. S. Bureau of Mines. Here, zirconium is produced in the form of a more or less massive sponge by the reaction of zir-

conium tetrachloride with liquid magnesium. Prior to the development of the Kroll process, zirconium had been produced by the de Boer process in which a crude form of the metal was refined by the thermal decomposition, on a heated filament, of zirconium tetraiodide formed by reaction of iodine with the crude metal. This latter process produces metal in the form of bars called "crystal bar" and involves an expenditure of $5 to $10 per pound over the cost of the raw zirconium reactant. The zirconium produced by the Kroll process is relatively high in volatile matter, such as magnesium and magnesium chloride, which is driven off during melting, and is also high in oxygen content. Otherwise its purity is similar to that produced by the more costly de Boer process and practically all commercial utilization of zirconium has shifted to metal prepared by the Kroll technique.

Both these methods are by nature batch processes and a number of other methods offering potentially lower costs have been explored. Thus, zirconium powder is produced by the reduction of the oxide by calcium. Calcium reduction of zirconium chloride or fluoride has been explored as well as electrodeposition from fused salt baths containing potassium zirconium fluoride. The prospects appear bright that a cheaper method of extracting zirconium from its ores will be developed. However, because of the high melting point of zirconium and the necessity for shielding the product when hot from the atmosphere, it is unlikely that its cost will ever approach that of metals such as aluminum or magnesium. Hence zirconium must be regarded as a metal whose unique properties may render its application to special problems economic in spite of relatively high cost.

SPECIAL MELTING METHODS DEVELOPED FOR CONSOLIDATING HOT ZIRCONIUM

Because of the rapid reaction of hot zirconium not only with constituents of the atmosphere but also with crucible materials, special melting methods involving inert atmospheres have been developed for its consolidation. The only crucible material in which zirconium can be melted without excessive contamination is graphite. Melts made in graphite crucibles contain consistently less than 0.15% carbon; note that zirconium is much less susceptible to carbon pickup during such melting than is titanium. However, even this small amount of carbon renders the metal unsuitable for certain corrosion applications, and therefore an arc-melting process has been applied in which the raw material is melted under an inert gas by an arc between a molten pool contained in a water-cooled crucible and an inert electrode or consumable electrode of compacted sponge. Undoubtedly the art of melting has reached one of its highest stages of development in this process, since 500 pound ingots, 12 inches in diameter are regularly produced without any appreciable change in composition other than loss of volatile compounds, and 1000 pound ingots are being planned. This melting step presently costs several dollars a pound but could undoubtedly be reduced drastically for high production rates.

Fabrication of small zirconium ingots is generally performed in copper or iron sheaths to prevent excessive contamination by the atmosphere during hot working. However, in the case of the larger ingots now being produced, hot forging, blooming, and rolling operations can be and are performed on the bare materials in commercial steel mill equipment with

so little surface contamination that sand blasting and pickling procedures normally used for stainless steel readily condition the surface. The cost of zirconium in the form of plate or rod is quoted by Zirconium Metals at $25 to $30 per pound and the economics of high production make it apparent that this cost will be reduced by a large factor when the demand requires quantity production. Standard zirconium shapes have been produced by practically all the conventional metal working processes such as extrusion, rolling, wire drawing, deep drawing, and spinning.

Zirconium can be welded by the inert gas arc welding process. Special precautions must be taken to purify the gas atmosphere if excessive contamination and embrittlement of the weldment is to be avoided even by this process. Thus welding boxes containing an inert gas atmosphere are often used for welding of zirconium. Torch brazing and furnace brazing of zirconium are feasible using a flux developed commercially for the brazing of titanium. The group of metals of which zirconium is a member has the unique property of being able to dissolve surface oxide and nitride films. Therefore the possibility of forming high integrity bonds by pressure welding either hot or cold is very good in case of zirconium. Joints are regularly produced by roll cladding between zirconium parts which show metallographically no trace of the original line of separation.

Zirconium parts may also be fabricated by powder metallurgy. The powder is generally prepared by reaction of the metal with hydrogen to form a hydride in which condition it is readily pulverized in hammer or pebble mills. The resulting powder can then either be reduced to metal by heating in vacuum at a low temperature or can be compacted directly by standard powder metallurgical techniques to form a green compact which is then sintered in vacuum at temperatures of 2000° to 2400° F.

Whereas zirconium is similar in crystal structure to the other hexagonal metals like zinc, magnesium, and beryllium, its mechanical and fabrication properties are quite different. It is extremely tough and ductile and retains this ductility in impact tests even down to liquid nitrogen temperatures. It is thus similar in its mechanical properties to the austenitic stainless steels and can be alloyed to show similar strength properties. Zirconium does not appear to have attractive high temperature properties and loses its strength rapidly above 90° F. In this respect its high melting point is deceptive and the transformation temperature at 1600° F. appears more representative of its high temperature properties. A troublesome characteristic of zirconium is its extreme galling characteristics. This can be illustrated by the fact that zirconium will even gall on glass, and in fact zirconium pencils have been used for marking glass. Many of the difficulties in fabrication of zirconium which have been ascribed to a deficiency of ductility can be traced to its galling characteristics.

ZIRCONIUM ALLOYS CONSIST MOSTLY OF ALPHA PHASE STRUCTURE

While in most respects zirconium is similar to titanium, important differences exist in its alloying behavior. Thus, while many of the titanium alloys that have been developed consist of the stabilized high temperature beta phase or a mixture of the low temperature alpha and high temperature beta

phases, practically all the zirconium alloys, utilized today consist almost entirely of alpha phase structures. Thus, the possibility of improving mechanical properties significantly by heat treatment is less marked in zirconium than in titanium alloys. Oxygen and nitrogen in even small amounts rapidly harden zirconium just as they do titanium. However, the hardening effect of oxygen is rapidly lost with increasing temperature so that at temperatures of 700° to 750° F. such alloys have the same mechanical properties as low oxygen material. Hydrogen is an omnipresent impurity in zirconium and can be picked-up in commercial furnaces even during heating for hot working. When present in amounts as low as 10 parts per million it can seriously affect the low temperature notch toughness of zirconium. It can be controlled to some extent by vacuum annealing and in any case has little effect on properties above 500° to 600° F.

Zirconium has high electrical resistivity and low thermal conductivity and again in these properties is similar to austenitic stainless steels. It is characterized by quite a low modulus of elasticity which is advantageous in many fabricated structures since this property minimizes build-up of excessive locked-in stresses. Helpful in the same respect is the low thermal expansion of zirconium; in this regard it is matched among pure metals only by molybdenum and tungsten.

It is as a result of its corrosion properties that zirconium will undoubtedly find its largest sphere of application outside of atomic energy uses. The only acids that attack zirconium are hydrofluoric acid, concentrated sulfuric acid, and phosphoric acid; in its resistance to hydrochloric acid, it is exceeded only by tantalum and the precious metals. Its resistance to alkalies is better than that of tantalum, titanium, or stainless steel. This property of being resistant to both acids and alkalies can be matched only by the precious metals. Several interesting applications of the corrosion resistant properties of zirconium have been made at the Bureau of Mines. Since much of their equipment must operate in environments high in hydrochloric acid, they have found that replacement of many of the standard parts in commercial equipment by similar parts made of zirconium has resulted in dramatically longer lived equipment.

The marked corrosion resistance of the material, its ease of fabrication and joining, its marked toughness, and freedom from internal stress effects offer considerable promise for the eventual application of zirconium in fields much broader than that of atomic energy alone. These same properties coupled with low cross section, make it an outstanding reactor structural material.

BERYLLIUM—INTERESTING EVEN THOUGH USELESS

Although pure beryllium has almost no industrial use, it has been the subject of numerous metallurgical investigations over the past 50 years. It is not surprising that it should have attracted this attention for it is lighter than aluminum, has good strength, a modulus of elasticity one-third greater than steel, good corrosion resistance to air and water, and a high melting point. The fact that it has not come into general use may be ascribed to its brittleness and high cost. Substantial amounts of beryllium are used industrially, however, as a hardening addition to copper and nickel-base alloys. An in-

tensive program has been carried on by the AEC during the past few years because of its very low absorption cross section and good moderating properties.

Beryllium is a fairly scarce element, occurring in the earth's crust to the extent of 10 to 15 parts per million. At the present time, the principal source of beryllium is the ore beryl which is produced only as a by-product in mining other minerals. Only beryl crystals large enough to permit hand-sorting are recoverable since no concentration process is yet economical. Up to the present, the supply of ore, although not large, has exceeded the demand. The consumption of beryl in 1952 was a few thousand tons; this quanitity of ore would permit the production of a few hundred tons of metal. No information has been made available concerning the supply problems that would develop if the demand for beryllium metal were to increase markedly.

Beryllium metal is usually produced by the thermal reduction of beryllium fluoride with magnesium, yielding a solid metal in either lump or massive form. The slag accompanying the metal is removed by washing and vacuum melting. A second process involves the electrolysis of a fused salt containing beryllium chloride and sodium chloride at a temperature below the melting point of beryllium, thereby producing a flake material. The price of beryllium of fairly high purity in the lump form is about $50 per pound and purification by vacuum melting adds perhaps another $5 or $10 per pound. Because of its low density, a pound of beryllium may go further than a pound of zirconium, for example. On a volume basis, as a matter of fact, the price of zirconium and beryllium are about the same.

The melting of beryllium is usually carried out in a vacuum induction furnace. The high chemical reactivity of molten beryllium prevents the use of any of the common refractories, and rather extensive investigations of a variety of refractory oxides, nitrides, carbides and sulfides have not uncovered a material better than beryllium oxide. As a result of the beryllium oxide crucibles used, the melts usually contain somewhat over 0.1% oxygen, which is the major impurity. The use of a vacuum in melting not only serves to minimize oxidation losses but results also in the elimination or reduction of a number of volatile impurities, such as the fluorides and chlorides of magnesium and sodium. A rather serious difficulty is experienced in making sound ingots from vacuum cast metal. If the cooling rate is too low, excessive reaction occurs with the mold material, while if the cooling rate is high, the resulting high temperature differential produces thermal stresses of a magnitude sufficient to cause cracking.

Blocks of beryllium are often fabricated by powder metallurgy methods, since the fine grain size obtained minimizes the unfavorable mechanical properties associated with the coarse grain size of ingots. The usual starting material is powder prepared by crushing and grinding vacuum cast ingot. Blocks as large as 50 inches long by 30 inches wide by 4 inches thick of nearly full density have been made by vacuum hot pressing of powders. Hot pressing of powders in air has also been used to produce blocks as large as 12 inches in diameter by 4 inches thick having practically full theoretical density.

The forging and rolling of cast beryllium either hot or cold almost always leads to cracking when conventional metallurgical techniques are used. If the beryllium is encased in a steel jacket, simple forging and rolling operations are possible. Extrusion, which minimizes tensile stresses, is probably

the best method for working cast beryllium but jacketing and special die design are required. Powder metallurgy beryllum may be worked with somewhat greater ease, but care must be exercised to avoid conditions that cause grain growth. There has been little or no success in swaging or drawing beryllium. The most successful joining techniques have been with inert arc welding, pressure welding and aluminum brazing.

The elongation of beryllium in a conventional tensile test at room temperature is usually in the range of 0 to 2% for fabricated cast beryllium and slightly higher for fine grained hot pressed material. There is evidence that the high content of beryllium oxide in powder metallurgy material improves ductility, presumably by acting as a grain refiner. By special extrusion techniques, substantially higher elongations may be obtained in the extrusion direction but the transverse ductility is then essentially zero. The brittleness of beryllium is also demonstrated by its extreme notch sensitivity which further prejudices its use as a structural material. There appears to be little hope of improving ductility. Metal of the highest purity obtainable has no better properties than commercial grades. Additions of various deoxidizing elements and solid solution alloying elements produce no improvement.

An increase in the test temperature produces a marked improvement in ductility, the tensile elongation exceeding 20% above 650° F.; this implies that slip or other deformation mechanism supplements or replaces the twining mechanism that prevails at room temperature.

In addition to its technical deficiencies, beryllium presents a serious health hazard. Ingestion of beryllium or its compounds by breathing or through an open wound may lead to berylliosis—a silicosis-like condition—or carcinoma, for which there are no certain cures. Sensitivity to infection varies greatly among individuals much like an allergy. Fortunately the problem can be controlled by industrial hygiene procedures and the incidence of illness among workmen can be reduced to an acceptable level.

This brief review indicates that beryllium compares favorably with zirconium on a price per unit volume basis, rather unfavorably with respect to potential supply, and very unfavorably with respect to ductility and workability. It appears unlikely that any significant improvement in ductility is possible and therefore it is probable that beryllium will not compete seriously with zirconium for structural applications. On the other hand beryllium is unique among metals as a moderator and it will be surprising if reactors are not built in which this property justifies its use in spite of mechanical difficulties.

URANIUM IS PRESENT MAJOR SOURCE OF ENERGY FROM FISSION

Uranium occupies a position in nuclear energy metallurgy that is rather more basic than either of the two metals discussed in that it is at present the major source of energy from fission. It presents many of the same metallurgical problems that are presented by zirconium and beryllium since it also is very reactive chemically, but it presents in addition rather more complicated behavior with respect to radiation damage. This results from the fact that fission produces within the uranium a wide variety of new "alloying elements" in substantial

amounts, and from the fact that the fission fragment energy is absorbed directly in the uranium. The most interesting aspects of its behavior however, being so closely associated with reactor technology, are classified and we shall attempt here only to mention a few of its more unusual characteristics.

Uranium can be fabricated to almost any shape by a variety of processes. Solid shapes and hollow tubes have been extruded and small diameter tubing and wire have been made by cold drawing. Conventional methods of rolling and forging can be used satisfactorily. The fabrication method which should be used in particular circumstances depends not only on the size and shape desired in the product but even more importantly on the fact that the properties of the metal can be varied considerably by the process used. This result arises from two general features common to most metals. The first factor is that some of the physical and mechanical properties of a metal vary in different crystal lattice directions. The low temperature form of uranium is a metal of very low crystal symmetry and, for example, the coefficients of expansion in the *a*, *b*, and *c* directions of orthorhombic uranium are 28, -1.4, and 22×10^{-6} per ° C. respectively. Thus, a single crystal of uranium when heated would expand in two directions but contract in the third.

The second factor is that, when metals are mechanically deformed, certain crystallographic planes and directions assume preferred directions with respect to the working direction and this preferred orientation tends to confer on the metal to some degree the anisotropy of properties of the single crystal.

Uranium may exist in any of three allotropic forms in the solid state: alpha which is orthorhombic up to 660° C., beta which has a complex crystal structure similar to the sigma phase in iron-chromium alloys from 660° to 770° C.; and gamma which is body-centered cubic from 770° to 1130° C., the melting point. There is a substantial difference in the plastic properties of the different phases. Alpha uranium has modest ductility at room temperature but becomes quite ductile at temperatures above 300° C. In the beta phase uranium is considerably less ductile. In the gamma phase uranium is very soft, softer in fact than high purity lead is at room temperature.

Uranium tarnishes on exposure to air at room temperature and oxidizes rapidly at temperatures above 200° C. Since its inhalation constitutes a serious health hazard and since it has a high dollar value, it is often necessary to protect the metal during hot working operations. For example, it can be jacketed in a metal like iron or copper as has been described for zirconium and beryllium.

By analogy with iron which also exhibits allotropic changes in the solid state, the alloying possibilities in uranium are obvious. It is therefore not unreasonable to expect that the transformations in uranium should make possible the development of alloys of improved properties of specific applications.

In this discussion of the three most important new metals that have received attention as a result of potential atomic energy applications, the progress that has been made in developing their metallurgy has been indicated. Unfortunately, no appraisal of the degree of success in meeting the needs of the reactor designer is possible without considering information beyond the scope of this article. Materials continue to be a very serious problem in power reactors. Nevertheless, materials are available from which feasible power reactors can be built. Only by building such reactors will the full scope of the problems be revealed and the ultimate solutions be discovered.

A BLUEPRINT FOR OPERATION AUSTERITY IN THE NAVY

By WESLEY HASKINS HAMMOND

THE AUTHOR

was engaged in chemical research under Mr. J. G. O'Neill at the Engineering Experiment Station in Annapolis, Md., in 1919 to 1921. In 1922 he became Assistant Chemist in the Mare Island Naval Shipyard where he remained until 1930. At that time he moved to Pearl Harbor where he was Yard Chemist and civilian head of the Industrial Laboratory until October 1943. When the new naval shipyard was opened in San Francisco in 1943, Mr. Hammond became Supervising Director of the Industrial Laboratory there and is currently in that position.

A policy of retrenchment, even when sufficiently rigorous to justify use of the phrase "Operation Austerity," is not a prospect to frighten experienced Navy men, either top management officials or middle management civilians. In fact, the history of the Navy is the story of living through such periods of privation, alternating with short periods of wartime sufficiency of men and resources. Navy personnel in the shipyard organizations have learned in such times of lean austerity to keep the ships in repair with the minimum of men and materials, and in readiness for the next build-up to battle strength.

Such a period of rigid economy, for instance, was normal management policy in the Navy between the date of the Washington Conference and the beginning of the expansion to meet World War II, approxiamtely 1938. While newer recruits, both officers and civilians, who only know the Navy in its peak era since 1938 may tend to dread the prospect, all Navy men of more than twenty-five years service have of necessity been drilled in austerity techniques. The old Navy was expert in taking in its management belt. For example, Captain Evans, Industrial Manager at Pearl Harbor in the middle thirties, customarily sent back to the Bureau at the end of each quarter up to one-half of his already meager operating funds.

There are some key principles, however, which should be deduced from the general historical pattern as a guide to the writing of the effectuating procedure, when and if a major operation of cutting is demanded by National considerations. If cut-backs

across the board are made blindly, or if a policy of natural attrition is followed, essential Shipyard functions must wither. The operation will either be guided by plan, or will become "Operation Drift."

The only feasible principle upon which to base the construction of the blueprint would seem to be an analysis of the findings of Naval management in the period 1920-38. Since Naval history is basically cyclic, and periods of contraction are recurrent, Naval men must learn to blueprint a smooth dip into a new low by studying Naval history. Since it is fundamentally the same Navy in high periods as in low, exclusive of changes due to the engineering design of the ships, and since the management problem is relatively constant, it would seem that much fumbling could be avoided if it were assumed that the organization in the next twenty years should approach as a limit the organization within the low period referred to.

This is particularly true of the shipyards with their mixed complement of line officers, reserve and special duty officers, and overwhelming preponderance of graded and non-graded civilians. Their very complexity makes the shipyards susceptible to experiments in reorganiation.

It is true that minor economies can be achieved in other ways such as by saving pennies in services. This kind of economy is tempting because it requires no fundamental thinking. In the mid-twenties, for example, the Mare Island chemical laboratory was rationed to three packages of paper towelling per week, or about one per person. This economy measure lasted about two months before its bad effect upon morale caused it to be abandoned. In the mid-thirties at Pearl Harbor a requisition for two pencils was automatically cut in half by top management. Some years later at another shipyard, which was plagued by dark and foggy mornings, it was directed to initiate and enforce measures to cut down overhead lighting in a certain building. A little investigation revealed that the lights which were in pairs, cost less than three cents per hour for electricity and maintenance. The cost of the supervisor's time for enforcing a satisfactory schedule of turning off the lights as outside sunlight increased during the day cost approximately 160 times that figure.

Another type of economy was tried by one Naval activity which utilized the time of a two-and-a-half dollar per hour technician to recover silver metal from a spent x-ray film fixing bath. The operation was successful—at a cost of the technician's time—but then management was faced with the further expensive problems of getting the metal taken up in Stock supply. If the price of the recovered silver had been properly calculated it would have been many times its value on the market.

It is true that middle management always has the responsibility of eliminating waste in use of materials and manpower; but attempts, such as the examples given above, by top management to squeeze further savings out of the details of operation, especially in use of services, usually produce lean pickings.

On the other hand some economies can be achieved by cutting down on paper work. Also undoubtedly further operating savings could be made if less time of supervisors were spent on the phone and perforce in conferences. During the austerity years between 1920 and 1938, the head of a Shipyard test and engineering services laboratory received an average of one printed

or mimeographed directive, procedure, memorandum or notice each month; at present the average middle management civilian in this or a similar position may receive around ten per day. At that time the Laboratory Supervisor attended or led no more than two conferences per month; the average can be several times that number per week now, sometimes that many per day. Around 1930, at Pearl Harbor, the Production Officer, the Shop Superintendent, the Electronics Officer, the Repair Superintendent, the civilian head of shops, and the Laboratory Supervisor shared three phones. Thus the use of a phone to discuss any but essential business was impossible. At that time, a whole department found use for four to eight typewriters. But any similar economies to be achievable now from lessening paper work, time spent in phoning or in conference, would still be considerably less than could be logically attainable by making cuts in those management personnel which exist to demand paper work, or time of supervision spent on the phone, or who call conferences.

All blueprinting for austerity inevitably returns to the necessity for eliminating people, which is a hard conclusion. The principle expense of operation is in wages and salaries. When the historical Naval cycle reached its high point of employment, it was management that added more functions, in addition to more people, in contrast with the production force which in general did not add more shops. If the wheel is to turn to approximately its 1930 position with relation to economy, it would appear logical to prune management functions.

While the necessity for a return to a management model of the twenties and thirties can be accepted as a first approximation, such a return should not be forced blindly by leaders who do not understand the needs of modern fighting ships. Engineering changes in the ships themselves require that a second approximation of our formula be sought. Not all of the management activities that have come into being since 1938, such as the electronics division, the expanded ordnance division, or the new types of engineering laboratory control test units, can be relegated to the limbo of sail-making and fueling by coaling plants. New laboratory developments such as spectrographic control of alloy stocks, metallurgical control of production heat treating by laboratory physical tests, and non-destructive test-control of production welding of ships' armor and high pressure piping by radiography, magnetic powder testing for cracks in heavy duty crane hooks, and ultrasonic testing for cracks and laminations in forgings, armor plate and fuel piping are essential extensions of control if the quality of workmanship in the modern shipyard is to keep pace with the increasing engineering complexity of the ships, the increased quality of the materials that go into them, and the increasingly critical nature of their political mission. Also, another example, the intelligence level and pay scales of Supply stockmen cannot be safely lowered if the increased complexity in stock items is to be safely controlled.

So the general principle of cutting down on activities that seem to make little essential contribution to the maintenance of fighting ships cannot be distorted into a blind wielding of an axe that results in sending out ships incapable of giving a good account of themselves in some sudden surprise encounter. "Fewer ships but better ships" is the only safe goal for management in an austerity period. Essential activities should be built up or cut back to a point of maximum return;

less essential activities must be cut back to a point of comparative return on the same basis, using the same yardstick. But this is a general yardstick, to be applied by the most intelligent administrative leadership, and with the necessity in mind of retaining in the fleet an engineering lead in offense and defense over any seaborne or air-borne threat.

The problem then develops of what to do with the less essential functions, when they are located by application of the yardstick, the so-called "luxuries" of the Navy. Some of these activities represent the hard work of able men. It is not to be expected that any going concern will willingly accept the label of luxury.

This detail can be solved by experienced leaders upon the basis of a comparative management analysis of the old Navy and the new. The present contribution to the efficiency of the fleet of each management activity in turn will have to be assayed. Typical questions that must be asked of each are as follows. "Was this group and their work considered necessary to the repair of ships in 1920–38?" "If so, have increases in size since that period been warranted?" "Have expansions been justified by increased service to ships, or is there evidence of empire building?" "Is this an obsolete service, made so by changes in the ships themselves?" "Is this a new service, justified in size and administrative complexity by new developments in the ships?" "Have expansions in this function contributed proportionately to increased fighting quality in ships, or does it contribute a 'luxury service' to the fleet?" "Was the initiation of this function, or its expansion, based on diversion or stealing of duties from older activities which could perform them better or more economically if they were returned?" "Does this function contribute concrete, real service, or is it purely advisory in nature, existing as a convenience to top management?" "Are the activities of this function contributory to the fighting efficiency of a small Navy, or is this solely a 'big organization' function?" "Is this a temporary function, retained beyond the expiration date of its usefulness?" "Is this a 'specialty' function, retained in an austerity period that cannot afford specialization of the particular type?" "Was this a 'war-baby' held over into the peace period?" "Was this function set up to plan future expansions that are now impossible?" "Was this function copied from private industry, without being contributory to Naval organization or to the repair of ships?"

An experienced Naval administrator can set up a series of searching questions of this kind that can be effective in discerning between the tares and the wheat.

For example, the case is under consideration of some engineering specialty, which may be a highly paid civilian position created since 1938. The incumbent has the responsibility of advising some department or division officer, and of writing orders for his signature pertaining to the specialty. A management analysis of the type suggested above might reveal some very important facts. Probably the position was created originally by taking functions away from older activities. The duty of keeping a special file on the subject of the specialty was transferred bodily from Central Files, resulting in making the information harder instead of easier to get. The duty of this specialist of giving technical information and direction to the shops was taken, partly from line supervision and partly from Design, and Planning and Estimating Divisions. Other duties which may have to do with relation to the affect of his specialty on the health of work-

men was taken originally from the Medical Officer. The job of conducting experimental work to improve shop practice in the field of the specialty was taken bodily from the Shipyard Laboratory. The job of writing official directives with regard to the specialty was an encroachment on top management responsibility. In the old Navy, top management administrators were trained in a hard school to reason from facts, secured from laboratory analysis or field observation. Decisions were made without the aid of special advisers, inserted between the executive and his facts. A consideration of all these data, dug out by a management analysis, might lead to the conclusion that these specialty functions should be returned to their pre-1938 exercisors for the duration of the austerity period.

With regard to the problem of retention of civilian specialists, another factor must also be considered, the effect upon the continued efficiency of the function of the alternating cycle of war and peace. Old line, non-specialized functions, such as Design, Progress, Central Files or the Shipyard Laboratory are organized to be group functions, and are self-perpetuating at a uniform level of efficient operation. If one progressman goes on leave or retires, an understudy immediately steps into his place. If some key man is lost, a written method or procedure is employed to keep the work of that man continuing without delay. Such a group function can be expanded in war and cut back in peace without undue strain. Specialty functions, on the other hand, depend on the knowledge of an individual who is considered to know all the answers in his field. In war times such a man (and his assistants, if he has them) when recruited from the Civil Service eligible list, is likely to be overburdened by responsibility. He is one man, working on three shifts to struggle with the exigencies and shocks of a war responsibility. Upon the other hand, in the succeeding peace period, he may well live out the balance of his service as a fifth wheel, with relatively little but routine questions to answer. Then, in the succeeding upturn of the cycle as the next war approaches, he may well be superannuated and merely an obstacle, at a time when the Shipyard needs every ounce of human effort applied to the lever.

It might be well in long range planning therefore to restrict civilians to group, or true organizational functions, which they are outstandingly fitted to perform efficiently throughout all changes in overall command. Specialty functions could be given to reserve officers, selected anew at the beginning of every emergency on the basis of demonstrated performance in private industry, to serve as true specialists for the duration of the emergency. This principle, by inference, would bar these industry-trained officers from placement in the middle management positions in which civilians are trained to serve. A system of restricting these specialty positions to the Reserve would confer several benefits, as well as bringing several far-reaching economies to the Shipyard, such as allowing immediate personnel reductions at the end of every emergency, give good peace-time training to Civil Service personnel who would have to widen their responsibilities to fill up the gaps, and it would give top management a chance to pick the best talent in the country during emergencies to perform these special functions.

In another case, we may find true management, non-specialty functions, which yet perform relatively non-essential duties in a time of austerity. The acid test is to probe their value with regard to the repair of ships.

These may be logistic, morale building, personnel handling, recreational, clerical, typing, correspondence duplicating, filing, planning, and other administrative services of all possible types, which expanded greatly in the big Navy. Some of these have to do with producing and transmitting repetitive quarterly reports. Others may deal with writing procedures, some to control shop operations where the shopman knows considerably more about the operation than the procedure writer. This is not to say that there are not other cases where effective engineering controls over production processes are not very badly needed. Some deal with endless personnel procedures. For example, before 1938 all efficiency ratings at Pearl Harbor were written by the Chief Clerk, not by the different supervisors, and Position Description Sheets were written by the supervisor, not by the incumbent of the position. If a man were allowed to retain his job, he knew that his efficiency was satisfactory; if he wanted to know what his job was, he asked his boss—he did not tell the boss. Whether this system was good or bad, filling personnel forms, processing them, reviewing them, returning them for rewriting, making changes in policy in regard to them, and filing them, required only a few hours per year of a few people, instead of many hours per day of many people.

A management analysis of the separate management activities which have developed since 1938 may find that many of them, employing hundreds of people, must be placed in the luxury class with reference to austerity thinking. Efficiency in this case would seem to demand that they be placed on ice. In other words, like the bear who goes into hibernation in hungry weather, they can be drastically abbreviated in activity, by being cut back to a nucleus of one or two people, around whom the functions can be rebuilt, if desired, in the next upswing. The important point would seem to be that whenever savings in administration must be made, elimination of the non-essential will be painful to the individual; but elimination of the essential will be destructive to the Navy.

Some of these services, in another example, are necessary only as part of a large organization, but become luxuries in a small. The philosophy which dictated their founding was big Navy thinking. This statement may be particularly true of some personnel handling activities. Crowding men together, particularly when done overnight and accompanied by psychologically-disturbing reorganizations, as is necessary when the Navy expands to meet a sudden emergency, generates personnel strains which necessitate greatly expanded morale building, personnel placement and transferring, grievance handling, personnel terminating, personnel rehiring, personnel training and indoctrinating, and similar services which could be listed at greater length. When the expansion energy is lessened, some of these services can be iced. In fact, line officers who have had experience with crew members pent up within the narrow quarters of a ship, and civilian supervisors with much experience in handling expanding groups of workers, know that small groups of men with plenty of elbow room to work to individual capacities, particularly when not badgered with less essential forms and paper work, require little administrative services except as furnished by the supervisor. A period of austerity is not necessarily a period of unhappiness for the worker.

Upon the other hand, it must be kept in mind that many old line functions have been tremendously expanded. Although there is a temptation to decide that such functions must be fur-

ther built up because of their importance to the repair of ships, a rigorous management analysis might demonstrate that they really need pruning. Some of these have non-essential personnel engaged in performing luxury services, concealed within the function. For example, a Navy photographic unit was once found to employ three typists. Since a Navy photographer's job is to make pictures of various shipyard occurrences for the record, and his output is prints and not letters, it is difficult to see why he needed al those typists. As long as Naval supervisors are expected to justify promotion, in any degree, upon the sizes to which they are allowed to expand their units, unhealthy growth in times of expansion must be corrected to a leaner working efficiency in times of austerity. The yardstick must be applied quantitatively as well as qualitatively.

This point of the effect upon personnel hiring of the tie-in with supervisory promotion deserves a little more attention. It is probable that this one item, the understandable desire of the supervisor to earn more income by increasing the number of his subordinates, has been the greatest single influence in expanding the size of the Federal service. The logical corrective would seem to be to make a 180-degree turn and reward supervisors for the FEW people by which they could get out a work-load, instead of by the number for whom they can write P. D. Sheets. For instance, in 1925 one chemical analyst, only, was employed at a certain shipyard laboratory to analyze material deliveries for qualification for purchase by the Naval District. About thirty, probably, are now employed by the same laboratory. It is hard to believe that thirty times as many samples are now processed by that Branch, or upon the other hand that each of those thirty chemists is that much inferior to the one man who did the work in 1925. It is easier to believe that the Chief Chemist was paid in 1925 for efficiency.

Something was said about personnel groups that are added to a Navy organization during an upswing, because such groups are considered normal to big organization thinking. Apart from the application of the rule that administration will expand in a definite ratio to work force, new groups may be added in order to produce a well balanced administration chart. The effort is to create a well-rounded, theoretically perfect bureaucracy, without specific reference to the repair of ships. Some of these functions may be found to be wholly in the luxury class, upon application of our yardstick. Viteles[1] remarks, "An organization may look perfectly sound on paper and still operate wastefully and with a great deal of friction because of the failure of the people to work together. On the other hand, the organization chart may show a 'crazy quilt' of relationships, but the company still functions smoothly and efficiently because the men and women who work for it—from the president to the most recently hired office boy—are willingly making full use of their knowledge, capacities, and skill in doing their jobs." The old shipyard was a very practical, efficient, cooperative working organization of a very few people.

Experienced shipyard workers do not object to assuming extra duties in periods of contraction. Considered psychologically, the reason seems to be that when the approach of austerity decreases the number of employees, and increases the responsibilities of the retained employee, it flatters the retained individual and gives him a sense of pride in being considered outstandingly good enough to be a survivor. The famous Hawthorne experiment

conducted by the Western Electric Company to determine the industrial psychology behind worker efficiency substantiates this point. It was found that making the worker feel that he or she was individually important to the company released a tremendous gain in worker output. As quoted by Chase,[2] "Their whole attitude had changed from that of separate cogs in a machine to that of a congenial group trying to help the company solve a problem. They had found stability, a place where they belonged, and work whose purpose they could clearly see. And so they worked faster and better than they ever had in their lives." It may be this feeling of "belongness" which is lost by shipyard employees at the crest of the wave, and regained, under wise management, during periods of austerity.

It is the conclusion of this paper that drastic economies can be made in shipyard management, provided that the blueprint is administered by experienced Naval leadership, and provided further that the basic experience of the preceding austerity period between the date of the Washington Conference and 1938 be used as a general guide line. Austerity was standard operating practice of the old Navy of iron men. Some of these men may still be left.

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HOW GOOD IS THE MAGNETIC AMPLIFIER?

ACKNOWLEDGEMENT

This article, written by J. J. W. Brown of the Industrial Engineering Section, Apparatus Sales Division of General Electric Company, was published in the July, 1954, edition of "General Electric Review."

If you had mentioned "magnetic amplifier" to engineers 10 years ago, you would have received a blank stare. Yet this comparatively "new" device was developed years before the electronic amplifier. For a quarter century it lay idle while industry focused its interest and attention on the electronic amplifier and, in later years, on the rotating amplifier, known as the amplidyne.

What brought about this paradoxical state of affairs? When the magnetic amplifier was first developed, a core material with the desired magnetic properties wasn't yet available. Neither did metallic rectifiers then have sufficient reliability and efficiency. And once set aside in favor of its electronic counterpart, the magnetic amplifier was for all practical purposes forgotten until shortly after World War II.

By then technology had advanced to the point where a device more rugged and reliable than the electronic amplifier was needed for certain applications. In the postwar years the magnetic amplifier has rocketed into widespread use.

Conflicting statements about the future of the magnetic amplifier were made during its infancy. Some engineers thought it was the answer to all problems in its field. Others felt the magnetic amplifier was just a flash in the pan, interesting because of its newness. But only now, after nine postwar years of industrial growth have given rise to many diverse applications, are we in a position to accurately appraise its worth or plot its future course.

CAUSE AND EFFECT

With certain exceptions the magnetic amplifier works similarly to most power amplifiers. A low-power-input current controls a higher-power-output current, the change in output being nearly proportional to the change in input.

Typical steady-state characteristics

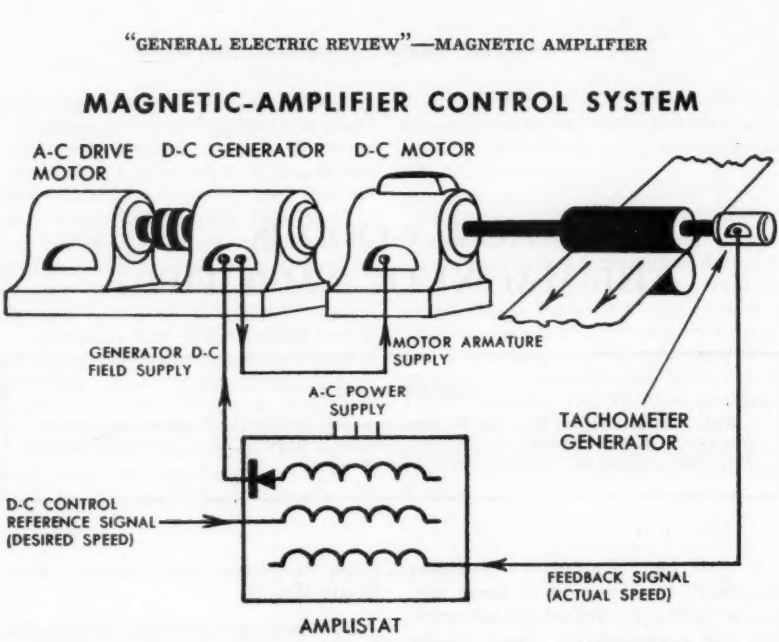

Fig. 1. THE MAGNETIC AMPLIFIER, or amplistat, is an electromagnetic device. A d-c signal applied to one or more control windings varies the magnetic permeability—and thus the impedance to the flow of a-c through an output winding—to produce an amplifying action; metallic rectifiers usually convert output to d-c. In this system the regulated quantity (actual speed) is compared with the input quantity (desired speed), and the difference is amplified to maintain an accurate match between the two.

of a magnetic amplifier, a rotating amplifier and a d-c generator, and an electronic amplifier are shown in Figure 2.

You can see that the magnetic amplfiier's normal operating range is selected so that its output increases almost linearly with input. The drooping upper portion of the curve is used only when the amplifier is overexcited, or forced, for short periods of time to obtain fast response. Although the curve is somewhat similar to the saturation curve of a d-c generator, you will notice that the magnetic amplifier's output does not reverse when its input signal is reversed. In fact, just the opposite happens: large values of reverse (negative) input current tend to increase output current in the forward (positive) direction.

This increase in output is opposite the normally expected results. And sometimes it can be most disconcerting if not considered in the design of a system. As a simple example of this effect, take a hypothetical situation where an operator is reducing the speed of a magnetic-amplifier-controlled d-c motor drive. Were he to decrease the control signal beyond the point where it reversed—changed po-

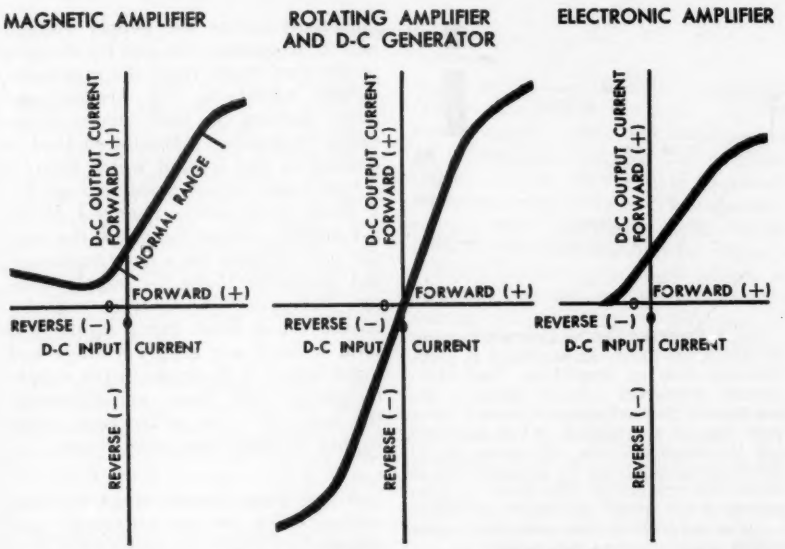

Fig. 2. MAGNETIC AMPLIFIER, like the electronic amplifier but unlike the rotating amplifier, is nonreversing. A reversed input signal increases its output in the forward direction.

larity—the drive would begin to pick up speed again. (However, recent techniques have minimized and practically eliminated this undesirable portion of the magnetic amplifier's characteristic curve.)

The magnetic amplifier is irreversible because metallic rectifiers are used in its output circuit. Where reversing characteristics are required, two magnetic amplifiers can be used whose outputs are opposed. This is, however, an extremely inefficient method. It is employed for relatively low power outputs where efficiency is of little concern.

As with all inductive circuits there's a time delay between the change in input signal to a magnetic amplifier and the corresponding change in its output. This time delay can be shortened by using a larger input signal, but then you also reduce the amplification. (A series resistance is added to the input winding to decrease input-circuit reactance.)

A magnetic amplifier's output appears as rectified pulses of its a-c input. And if you increase the magnitude of the input power sufficiently, you can approach the theoretical minimum time delay—one-half cycle of the a-c supply frequency. Thus the higher the power-supply frequency the faster the magnetic amplifier can be designed to operate. For this reason power-supply frequencies of 400 cps for power magnetic amplifiers and in the kilocycle per second range for control magnetic amplifiers are quite common.

The characteristics of a magnetic amplifier are changed not only by

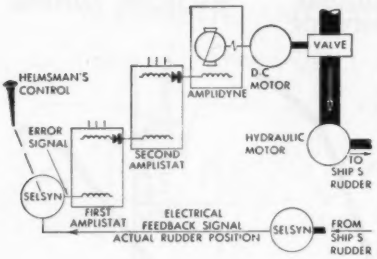

Fig. 3. STEERING ENGINE CONTROL systems of destroyers utilize an amplistat in combination with an amplidyne. Two electrically connected selsyns compare the position of the helmsman's control lever with that of the rudder. When they are not in correspondence, the error signal generated is amplified by the amplistat to excite the amplidyne. The latter in turn excites a d-c motor that opens or closes a valve controlling the hydraulic motor which actually moves the rudder.

variations in the a-c supply voltage and its frequency but also by changes in the load itself. Near the maximum output conditions, the predominant factor limiting the load current is the load's impedance. (Maximum load is defined as that load at which there is a maximum output power change for a given input power change.) If the a-c supply voltage increases, the output will increase for a fixed input signal. Likewise, if the a-c supply voltage decreases, the output will decrease for a fixed input signal. For both a fixed a-c supply voltage and input signal, a decrease in the supply frequency will have approximately the same effect as an increase in the supply voltage—and vice versa.

All of these factors must be considered when you use a magnetic amplifier.

IN ITS FAVOR

One way to judge the true worth of the magnetic amplifier is to compare its characteristics and features with those of competitive devices—namely, the electronic amplifier and the rotating amplifier.

For reliability the magnetic amplifier is preferable to the electronic amplifier. What it amounts to is a choice between an amplifier with long-lived, stable, and rugged components versus one equipped with vacuum tubes having a long but still unpredictable life.

From the maintenance standpoint the magnetic amplifier is preferable to the rotating amplifier. For it's a completely static device versus one with bearings, brushes, and a commutator.

Judged, therefore, on the basis of reliability, freedom from maintenance, and simplicity of components, the magnetic amplifier has no peers.

In speed of response the magnetic amplifier, in general, can only *equal* the rotating amplifier with difficulty. It can only *approach* the electronic amplifier in speed if it is designed for a high-frequency power supply—say, 1000 cps or higher.

The magnetic amplifier shares with the electronic amplifier the irreversible characteristics of the rectifier, whether metallic or vacuum tube. (For reversing applications the rotating amplifier is supreme.) On the other hand, it shares with the rotating amplifier the distinction of having its various input signals completely isolated. Because of this, magnetic amplifiers can be readily connected in series.

Further, a magnetic amplifier's components can be sealed for protection against adverse environmental conditions. And it can be constructed to withstand shock and vibration better than either rotating or electronic amplifiers.

HOW GOOD?

In many applications a magnetic amplifier is used where its only advantage is the character of its components. In other words, the amplifier's reactors, metallic rectifiers, and resistors can all be mounted in cabinets containing relays, contactors, and meters of the over-all system. Also, because the magnetic amplifier can be completely sealed, high altitude and similar environmental applications can dictate its use.

For applications where only a few watts' output is required, the magnetic amplifier will be smaller than either the electronic or rotating amplifiers. In this instance all its components can be sealed in a single can.

Because magnetic amplifiers are essentially power amplifiers, they are particularly useful for low-voltage high-current applications. Still, they can be designed in the same physical size to accommodate any combination of voltage and current for a given power output. By way of contrast. electronic amplifiers are voltage amplifiers with essentially high-voltage low-current outputs. And for higher-current outputs, you must resort to larger electronic amplifiers because voltage amplification is inherent to them—it's there whether you want it or not.

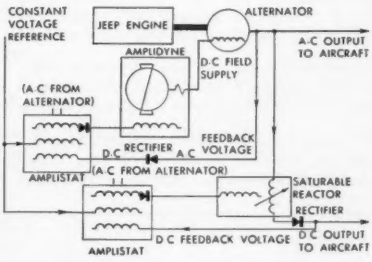

Fig. 4. MOBILE POWER SUPPLY for jet aircraft—such as the Navy's McDonnel *Banshee*—employs an amplidyne-amplistat system of regulating voltage. The jeep's engine drives an alternator that furnishes the aircraft with d-c power by means of a rectifier. Holding this d-c output voltage constant is a series saturable reactor. An amplistat controls the impedance of the reactor by comparing output voltage with a constant reference voltage. The amplistat is admirably suited to this application.

In the higher power ratings—10-kw and above—a magnetic amplifier becomes quite large and bulky. It needs more room than an equivalent-rated rotating amplifier. And for reversing output its size would be almost prohibitive. In addition, maintenance and the possibility of trouble increase in the higher power ratings. A 10-kw rotating amplifier, on the other hand, needs no more maintenance and is no more likely to fail than a unit rated 1 kw.

As stated before, the input signal to a magnetic amplifier is completely isolated from the output signal—a particularly useful feature when you must employ several input signals to control an output. Again, in this application the magnetic amplifier is most useful in the low power range—500 watts or less—where a rotating amplifier is quite large and bulky in comparison. An isolated input, incidentally, is difficult to obtain with the electronic amplifier.

Magnetic amplifiers can be designed for greater long-term electrical stability than either the rotating or electronic amplifiers. And so they are the logical choice for metering applications or for amplifying the output of millivolt shunts and thermocouples.

Their long-term stability suits them particularly to pure amplifier applications where no feedback is used and where variations in characteristics would affect output directly.

The magnetic amplifier is employed in many diverse applications. A partial list would include the minute outputs of photocells and ionization chambers, controlling the output of arc welders and the speed of paper-mill drives, and obtaining isolation in metering circuits involving thousands of amperes. Magnetic amplifiers have been applied to systems ranging from compact autopilots for aircraft to the largest high-speed motor drives for steel mills; from the regulation of voltages of miniature aircraft alternators to those of huge steam-turbine-driven utility generators.

THE SUMMING UP

In all its applications the magnetic amplifier has proved to be sturdy, reliable, and effective. But you can determine its true value only after making a thorough analysis of the application itself. For one purpose it may be superior to all other amplifiers; for another, it may be the poorest choice.

All of this means that the magnetic amplifier will not replace the electronic or rotating amplifiers in the immediate future. Instead, it will remain an additional amplifier tool with clear-cut advantages for some applications and equally clear-cut handicaps for others.

Although the magnetic amplifier will no doubt take an equal position with its predecessors, the electronic and rotating amplifiers, you can be sure it won't take a dominant one.

NEW SULZER ENGINE HAS UNCONVENTIONAL FEATURES

P. H. SCHWEITZER

THE AUTHOR

Professor in Charge of Diesel Research, The Pennsylvania State College, received his M.E. degree from the Technical University of Budapest and his Dr.Eng. degree from the Technical Institute of Dresden. He came to this country in 1920 and, after working for the DeLa Vergne Machine Company and General Motors Corporation, joined the Pennsylvania State College in 1923, as Assistant Professor of Engineering Research and became Professor of Engineering Research in 1936. At that institution he has initiated and conducted research on diesel engines and related subjects ever since. For 25 years Dr. Schweitzer also acted as consultant to prominent diesel manufacturers on design and development. Since 1952 he has been Partner in Schweitzer & Hussmann Engineering Office, Engine Designers and Consultants, while maintaining his connection with The Pennsylvania State College.

He is a member of American Society of Mechanical Engineers, Society of Automotive Engineers, American Society of Naval Engineers, Coordinating Research Council, Society of Sigma Xi, and Fulbright Scholar 1953-54.

Dr. Schweitzer is author of a book, "Scavenging Two-Stroke Cycle Diesel Engines" and well over a hundred papers and articles on engines, sprays, instruments, fuel testing, high altitude lubrication, etc.

The latest marine engine of Sulzer Brothers has many unconventional features but retains the time-proven advantages by the well known Swiss firm, a pioneer in building large two-stroke cycle engines. The need for such an engine arose by the demand for power outputs over 8000 bhp when twin-screw installations are necessary to avoid the use of extremely large engines requiring headrooms of over 40 ft.

The new engine, type R S 58, has 22.8 in. bore, 30 in. stroke, and has a rated cylinder output of 520 bhp at 240 rpm. It is principally designed for multiple unit geared installations. The 10 cylinder unit as shown in Fig. 1, develops 5000 bhp at 230 rpm. The engine is built in units from four to twelve cylinders and one to four engines may be geared to one shaft. Fig. 2 shows the propulsion plant for the Dutch motorship "Willem Ruys."

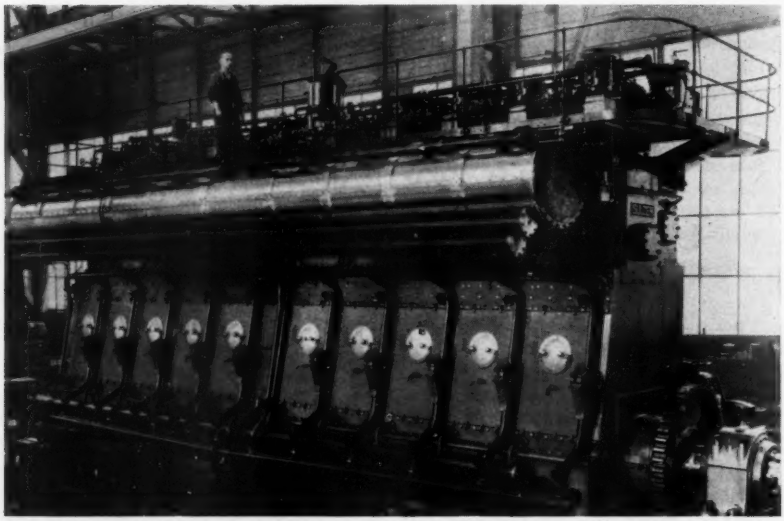

Fig. 1—Prototype of the new RS 58/76 engine on the Test Bed. With ten cylinders of 580 mm bore and 760 mm stroke this unit develops 5000 bhp at 230 rpm in normal service. The picture shows the exhaust side and the driving end.

With the adaption of gear drive eight Sulzer RS 58 8 cylinder engines driving two propeller shafts with a total shaft output of 3000 hp. made such a low headroom possible that it allowed to carry two additional decks over the engine room.

Although they have cross heads, desirable for heavy fuel operation, these engines are only 18 ft. high and require a head room not over 23 ft. for servicing. How this became possible will be made clear from the subsequent description.

The cross section of the new engine is seen in Fig. 3. It has a welded steel construction yet the familiar Sulzer cylinder design, except for the use of a single row of inlet ports and a supercharge valve in the exhaust ducts, new with Sulzer. The most striking feature of the engine is the very short piston and stuffing box around the piston rod.

The old engines had very long pistons (three times diameter) which acted as crossheads satisfactorily but had two disadvantages. First it made for a tall engine, second in using poor quality heavy fuels combustion residues containing sulphuric acid and abrasive matter found their way into the crankcase causing corrosion and wear.

In the new design the engine height is reduced considerably and the cylinder space is effectively sealed from the crankcase.

Such a short piston, however, is only possible when at top center a blow-through from the inlet to the exhaust ports is prevented. The supercharge

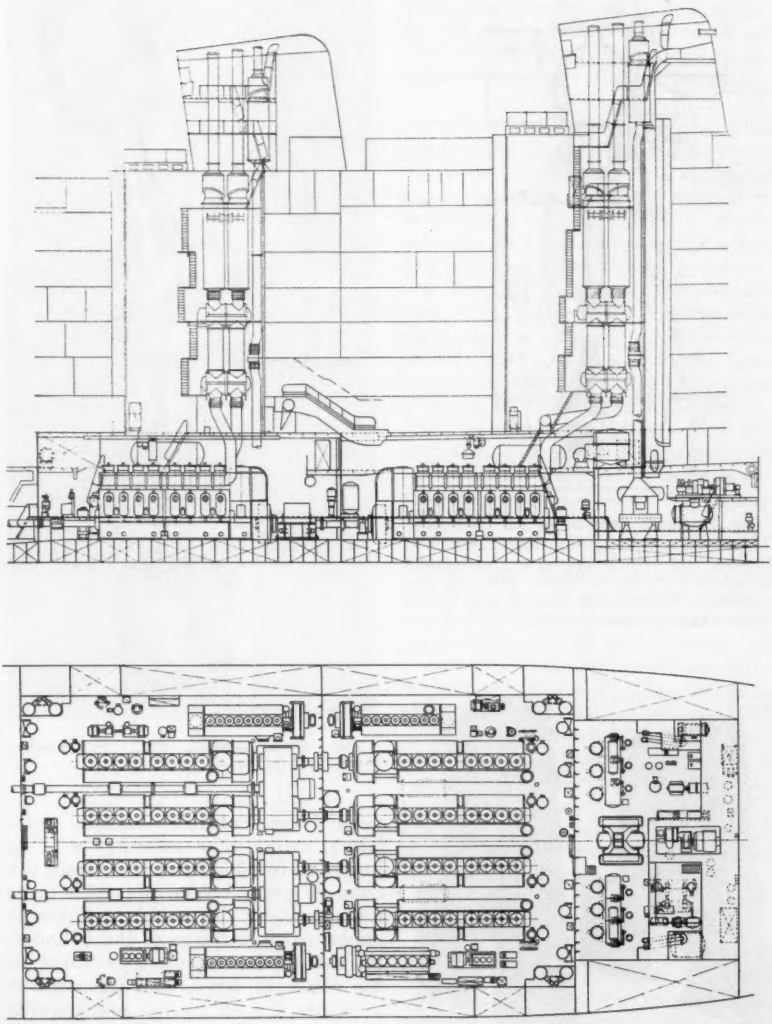

Fig. 2—Propulsion Plant of Dutch Motorship "Willem Ruys." The two propellers are driven by eight engines. Note the low headroom.

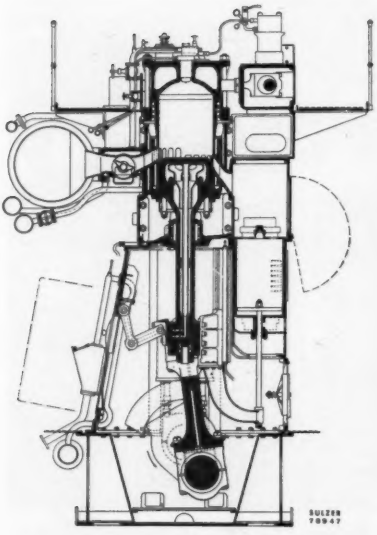

Fig. 3—Cross Section of RS 58 Sulzer Engine. Note short piston and piston rod stuffing box which prevents deleterious combustion products from entering the crankcase. Oscillating supercharge valve in the exhaust duct at right.

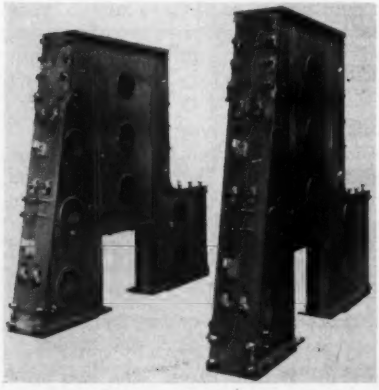

Fig. 4—A Frames of the RS 58 Engine. The recesses at the back take the scavenge-pump block which also carries the crosshead guides and helps to give the engine longitudinal rigidity.

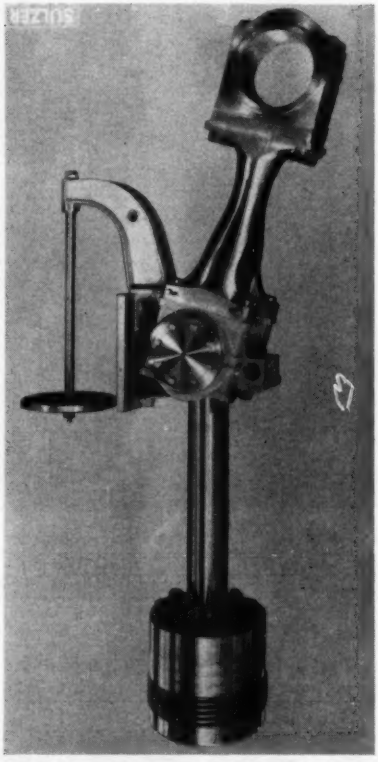

Fig. 5—Crosshead with Scavenging Pump and its Drive.

valve which incidentally is only oscillating, rather than rotating, is doing just that. In addition it also closes the exhaust ports before the inlet ports are closed by the piston and thus it effects a supercharge of the cylinder. So the Sulzer supercharge valve in the exhausts serves two purposes, it increases the air charge and permits a short piston. Naturally the well known automotive flap valves in the inlet have been dispensed with.

The box like welded A frames of the engine are shown in Fig. 4. The recesses at the back take the scavenge

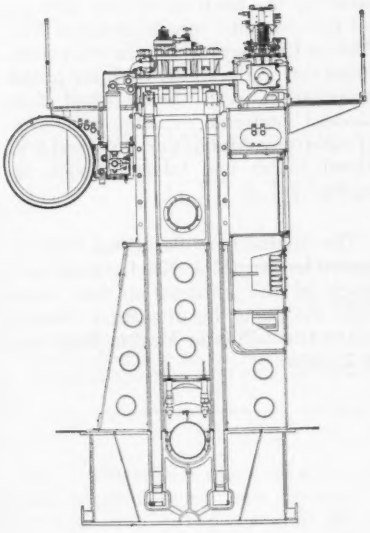

Fig. 6—Cross Section through Tie Rods between cylinders.

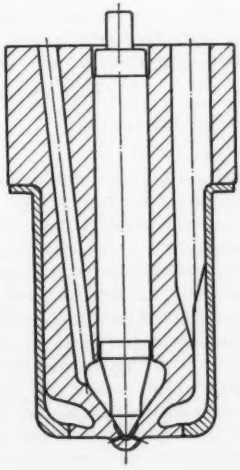

Fig. 7—Injection Valve with Intense Nozzle Cooling Specially developed for Operation with Heavy Fuel.

pump block which also carries crosshead guides shown in Fig. 5. The piston rod of the individual scavenge pumps is rigidly attached to the crosshead in the simple manner shown.

The steel frame is not depended on to withstand longitudinal forces. These are carried by the tie-rods shown in Fig. 6, extending from the bottom of the bedplate to the top of the cast cylinder blocks. Pre-tensioning of the tie-rods places cylinder blocks, A-frames, and bedplate under a compression such that even under the ignition forces they are free from any tensile stress. As the tie-rods have been brought as near as possible to the main bearings, no room is left to secure the main bearing caps by means of the normal stud arrangement. Instead jack screws are used to hold down the bearing caps, which has proved very satisfactory.

This design resulted in a very compact and yet rigid engine giving excellent performance in shop trials including a test run of 235 hrs. duration, 160 hrs. of which was on heavy fuel (1700 Saybolt sec. at 100 F). The fuel consumption at full load lay between 0.370 and 0.375 lb./bhp-hr. The fuel consumption curve was strikingly flat, in the region between ½ and 110% load varied only by some 0.005 lb./bhp-hr. The scavenge air pressure was 3.4 psig and the exhaust temperature 610 F. at full load (64.6 bmep) and 225 rpm.

As it was indicated, particular attention was paid in the design to heavy fuel operation. An injection valve with intense nozzle cooling was specially developed. It is shown in Fig. 7. The fuel pumps have larger clearances and are mounted at cylinder head level (Fig. 3) permitting very short injection lines. Thus the flow resistance to high viscosity fuel is reduced and it is no longer necessary to heat the high-

pressure lines. The injection timing is adjustable during operation. Even with fuels of 7000 Saybolt viscosity the nozzle was free from carbon deposits after 51 running hours.

Of course operation on heavy fuel requires a strict procedure in heating and cleaning and the installation of the necessary apparatus such as fuel heaters, centrifuges, circulating pumps and heated piping which will complicate the plant and increase its cost. For instance for treating fuels of 6000 Saybolt for a 5000 hp. installation five centrifuges are necessary. On the other hand by the addition of only 12% gas oil the viscosity can be reduced from 6000 to 1500 Saybolt where two centrifuges can do the work. With the proper preparation even the heaviest fuels showed moderate cylinder wear (approximately double that obtained with diesel fuels) and tolerable soot deposits.

The engine here described was designed by Mr. W. A. Kilchenmann and much of the information was taken from the paper he presented recently to the Institution of Marine Engineers in London.

DEVELOPMENTS IN INSULATION FOR ROTATING MACHINERY

ACKNOWLEDGEMENT

This article, by G. P. Gibson and G. L. Moses of Westinghouse Electric Corporation, discusses recent advances in insulation for rotating machines. It was published in the July 1954 issue of "Westinghouse Engineer."

The "CHEMICAL REVOLUTION" has made possible many new insulation materials and processes that have been significant factors in the redesign of electric machinery. Early electric motors and generators were perforce insulated with materials occurring in nature. Chemists and physicists have contributed a better understanding of why materials insulate, and thus the knowledge leading to better insulations. Furthermore, they have made these better materials with more closely controlled characteristics, as well as more consistent purity, than was ever possible with natural materials. As a result of this newest industrial revolution, insulation engineers have been active for the past decade providing new insulating materials and systems that are now being used in modern electric machinery.

INSULATION STANDARDS AND GENERAL CONSIDERATIONS

Insulation for rotating machines involves quite different design approaches and application techniques than are employed in the insulation of stationary apparatus. Many problems encountered in rotating machines do not exist in stationary equipment. For example, rotating machines must contend with centrifugal forces. The importance of space and weight in rotating machines, coupled with the greater need for physical support of the coils, requires solid barrier insulation on many parts. This is particularly true on those portions of the winding embedded in the core, where close capacitive coupling exists between winding and magnetic core. Furthermore, a much higher percentage of the winding is closely adjacent to the grounded magnetic core. Therefore, full-voltage insulation is commonly employed between all of the winding and the core.

The design of rotating machines, as well as other electrical equipment, is greatly affected by competition and customer requirements. These emphasize the need for lower cost and increased reliability. Many times a reduction in size means a reduction in

cost. Progressive steps have been taken in this direction. Significantly, many of them have been accomplished by reduction in space allowed for insulation, permitting a greater proportion of iron and copper in the machine. Other gains have been made by simplifying or mechanizing insulating processes.

Rotating machines span a wide range of cost, size, and complexity. At one extreme are those of thousands of kva or horsepower; these are largely tailor-made — each is ordered, designed, and manufactured separately and may never be duplicated. Then come those of a few horsepower, and at the other end of the scale the small fractional-horsepower motors; these are made almost completely by mechanized production lines. The requirements for rotating-machine insulation thus include many widely different problems.

Thermal endurance of insulation is an important limiting factor in electric machine design, and in this field the most obvious gains in electrical insulation have been achieved. The first AIEE standards (established about 1914) classified insulating materials according to their abilities to operate at different temperature levels. This standard outlines the general principles upon which temperature classification of electrical insulation is based. When insulations were first classified as to limiting temperature, the definitions were relatively simple because all the basic components existed in nature. Therefore, the materials fell readily into two classes—organic and inorganic. Temperature limits were selected on the basis of whether organic or inorganic components were used. Subsequently, it was recognized that organic materials fell into two subclasses—those composed entirely of fibrous organic constituents (class O), and those in which the fibrous components were further protected by impregnation with varnishes or immersion in liquid dielectrics (class A). the inorganic class B components described in AIEE Standard No. 1 had obvious uses. Mica was a dielectric barrier. Asbestos and later fiber glass were insulating spacers.

The advent of synthetic insulation materials greatly complicates the problem of classifying insulations according to the original definitions. Compounds can no longer be defined simply as organic or inorganic, nor can the problem be solved by interposing an intermediate class of semi-inorganic materials. Even the truly organic materials have vastly different levels of thermal endurance, as well as differences in physical properties, because some synthesized materials are better than their counterparts in nature.

Classifications of insulating materials and systems have been re-examined. Two distinct schools of thought are current. A group of engineers in Europe has proposed (under the sponsorship of the International Electrotechnical Commission) the creation of new classes of insulation intermediate between the now existing classes A and B, and B and H. They further recommend segregation of insulating materials into these classes on the basis of opinions of those who have used them. While many of the opinions underlying this classification are the result of individual tests and experience, no standardized testing procedure or common criteria of insulation evaluation is involved.

The second group is composed of electrical engineers in the United States working under the sponsorship of the AIEE. The objective is standardization of test methods and criteria whereby not only insulating materials, but complete insulation sys-

tems can be evaluated in terms of time and temperature to failure. This group has developed a functional evaluation program with proposed standard test methods resulting in measurable end points of insulation life. Many manufacturers and users are now evaluating different insulation systems by the use of model motors under standard methods. The program of this group is ultimately to adopt definitive test methods for determining the heat endurance of insulating materials.

Westinghouse has experimented for over 15 years in evaluating insulation on models of motors and parts of motors, as well as on complete small integral-horsepower motors. This has convinced engineers following these tests that standardized test methods and agreed criteria form the only sound basis for classifying both insulating materials and systems.

NEW INSULATING MATERIALS

Fibrous glass has grown from a laboratory novelty to an essential component of every large high-voltage generator and is being used on many small integral-horsepower machines. Its use is still growing. Fibrous glass meets the "inorganic" requirement of class B and H insulation, but is also being used in class A insulated apparatus, because of its desirable qualities and its drastically reduced cost. The outstanding physical strength of fibrous glass, the immunity of the fibers to thermal aging, and inertness to attack by chemicals and moisture have led to its use wherever justified economically.

Wire enamels have also improved significantly. A new resin for this purpose, developed at the Research Laboratories, is applied to wire for the new Life-Line A motor. Called Bondar, this resin enamel has excellent thermal endurance—at least two to three times that of previous enamels, as established by wire tests and tests on complete motors. It also exhibits superior resistance to refrigerants, such as Freon 12 and Freon 22, and has high dielectric strength.

The progress in wire enamels has made it possible to insert the windings of fractional-horsepower motors completely by special winding machines. Also, many of the space-consuming barriers and similar insulation materials have been eliminated on single-phase fractional-horsepower motors as a result of the improved insulation on the wire. The development of wire enamel having good resistance to thermal shock makes it possible to wind fractional - horsepower split - phase motors for severe starting applications without cotton covering or other space-occupying material on the starting winding wire.

The contributions of resin chemists to electrical insulation are extremely important. New synthetics have been created that serve as varnishes for impregnation of insulation, for bonding structural parts, and for finish coating surfaces of both insulation and metal. Silicone resins and their tremendous thermal stability are intriguing and an outstanding development, but the conventional organic resins must not be overlooked; they provide strong, and sometimes resilient bonds for insulation and fill the insulation interstices to an essentially void-free condition.

Silicones — Silicone varnishes and class H insulation have overcome severe operating problems where equipment is overloaded or operated in high

ambient temperatures. Silicone rubber is a promising new materials that provides dielectric barrier action. It has good dielectric strength on short-time tests, and excellent voltage endurance. Rubbery materials have a degree of fatigue resistance plus flexibility, resilience, and an ability to endure shock, which fits them to withstand prolonged mechanical vibrations and repetitive elongation and contraction. However, organic rubbers, have too short a thermal life to permit their use as a major insulation in important electrical machinery. Silicone rubber, however, possesses the essential characteristics of organic rubbers plus outstanding thermal endurance. In addition, silicone rubber has outstanding chemical properties. Absorbed water does not materially affect power factor, dielectric constant, or dielectric strength, as is the case with well-known organic materials. The weathering and corona resistance of silicone rubber are also unique among rubber materials. This opens the way for its use as insulation ground wall. Considering all of its characteristics, silicone rubber some day will probably find use as a ground insulation on important electrical machinery, but more work is needed to solve application problems.

Silicone resins are being used as enamel to coat bare wire and for treating glass-covered magnet wire. Mica products are available with silicone-resin bonds; these products include permanently flexible types and the hard molded plate and complex shapes. Certain silicone resins are useful for impregnating coils and windings. These high-temperature resins are used to coat fiber-glass cloths, as well as to coat coil surfaces, and as a finish for assembled electric machinery. In general, silicone resins do similar jobs to their organic counterparts with improved thermal endurance and moisture resistance.

The outsanding thermal endurance and excellent moisture resistance of silicone resins have resulted in ever-increasing usage. These resins have been employed in electrical machinery for more than ten years in connection with mica and fiber-glass insulation components. The composite insulation has been classified in AIEE standards as class H insulation with a permissible hot-spot allowance of 180 degrees C. The U. S. Navy has recognized this class of insulation as capable of continuous operation at hot-spot temperatures up to 200 degrees C. Much equipment with class H insulation has been in service for five years or more with an excellent operating record. Accelerated tests have been made at temperatures up to 300 degrees C, indicating that 200 degrees C hot spot is a satisfactory value for reasonable life. Motors in this test program, operating since 1943 at 240 degrees C., have accumulated 40,000 hours without trouble.

In conventional class H equipment, wherein silicone resins are substituted for organic resins in connection with mica and fiber glass, experience with class B insulation can be extrapolated to the class H temperature range. Laboratory tests and field experience correlate so that silicone insulation can now be applied to most types of electrical machinery where some economic advantage can be derived from it. Newer and more radical class H insulations in which resin films are substituted for the mica-flake dielectric barrier are being evaluated. These resins are either coated onto fiberglass cloth or impregnated into the interstices of inorganic paper-like structures, some of which are made from pulverized mica particles. In evaluating new materials of this sort, engineers should not presume that an insulation fits into a class whose characteristics have been proved merely because it contains particles of the

same basic constituents. To be consistent, these materials should be subjected to the same functional evaluation tests recommended for other new classes of electrical insulation.

In the case of fractional-horsepower motors the silicones have not resulted, as yet, in the same advantages as for larger machines. This is brought about by parts other than the winding insulation being adversely affected by elevated temperatures. In these motors small temperature gradients exist between the winding and the mechanical parts of the motor. Also, the relatively long low-temperature curing cycles prior to the final setting bake of silicone varnishes are not adaptable to the high-production methods of fractional-horsepower motor manufacture. Recent changes show promise of improvement in this respect.

Improved Organic Resins—New organic resins with vastly improved physical, electrical, and fabricating characteristics have made possible tremendous advances in the insulation of some kinds of electrical machinery. Several new resins have been developed which have excellent film-forming properties and provide great dielectric-barrier strength. Examples of these are Mylar, Teflon, nylon, and cellulose acetate, as well as many polyvinyl resins. Some have limitations in thermal endurance, others have poor voltage endurance; therefore a more complete evaluation is necessary to determine their full value. Some resins are ruled out because they flow under concentrated pressure.

Many synthetic resins can be formed into large sheets of thin, hole-free films. This can be an important advantage. Many appear to hold great promise for use as the main insulation in low-voltage, low-temperature classes. These are being studied and their position evaluated, but mica is still the most reliable high-voltage insulation for important machines. Mica may, in turn, be better applied when supported on some of these new films.

Mylar polyester film, one of the newest of these resins, has quickly developed into an important item in the insulation engineer's material list. It has extremely high dielectric strength. Its tear strength, particularly without an incident notch, is exceptionally good. These, together with other qualities, make it suitable for slot insulation, requiring less than half the space of previously used materials of similar qualities. Thermal-endurance tests indicate that Mylar retains these qualities, and has a useful life at temperatures somewhat above the 105 degree C maximum value allowed for class A insulation.

Mylar film has already found its way into small integral-horsepower motors. In the new Life-Line A motor it is used in combination with rag paper as slot-cell insulation. This combination has about twice the tear resistance, and half the thickness of the material it replaces, for the same dielectric strength. This film is also being used as a wrapper on small d-c motor coils. In fractional-horsepower motors this thinner slot-cell insulation will allow further winding reductions by permitting better utilization of copper and iron within the motor enclosure. In some designs this would allow the use of aluminum wire in place of copper, where desirable, because of material availability.

The wound stators of the new Life-Line A motor are dipped in an organic varnish that provides many improved characteristics. Called Bondite, the new varnish has a life at elevated temperatures of 170 per cent that of the previous varnish. It has excellent resistance to oils, solvents, acids, and alkalies. Fortification with silicone has

also provided greater water repellency, an important factor in many applications.

Another important resin development is the solventless heat-reactive resin impregnant. One class of these solventless impregnants brought to reality the insulation engineer's dream of "complete impregnation." Since insulation impregnation was first attempted, engineers have been striving towards the complete fill of the internal voids of an insulation to improve its electrical and physical properties. Unfortunately, they had only two types of materials—one was the varnish employing solvent, and the other was the plastic semiliquid asphalt-like bitumen materials. The solvent type was used in most impregnation work because of its ability to penetrate the deep-seated insulation interstices. But evaporation of the solvent left voids that could not be filled. The thermoplastic bitumen material was so viscous and of such great molecular size that it could not be thoroughly forced into most insulation structures even at the highest practical impregnating temperatures. Therefore, the creation of a low-viscosity solventless material that reacts completely when heated, without the evolution of gases or solvents, was an important step.

Thermalastic insulation is an outstanding example of achieving optimum physical, electrical, and thermal properties in such an insulation without sacrificing any of the known characteristics of mica. The solventless synthetic-resin varnish employed for impregnating Thermalastic insulation is one of the most valuable contributions of research to the insulation art. Because of its low viscosity before reaction it penetrates deeply into interstices of complex insulation structures with simple processing. When cured, its resilience, physical strength, excellent electrical properties, thermal stability, and water resistance have opened up new vistas of insulation potentialities still under development. Its ability to fill voids completely has made it a "natural" for high-voltage machine insulation.

This insulation had its inception in the Westinghouse Research Laboratories in 1940. It was first used commercially on large turbine-generator stator windings in 1949, and has since become the standard insulation for all electric-utility turbine generators built by Westinghouse. Also, it has been applied to all armature coils for large salient-pole generators, such as water-wheel generators. A modified form of Thermalastic insulation is being supplied on nearly all synchronous and induction motors of 200 hp or more. Among its outstanding properties are: (a) higher dielectric strength and greater voltage endurance; (b) fewer internal voids, with better heat transfer and reduced internal ionization; (c) resilient insulation system with great physical strength to withstand thermal cycling forces in very long coils; (d) low power factor, less affected by voltage and temperature; (e) chemical inertness; (f) outstanding moisture resistance; (g) greater thermal endurance and longer life.

OTHER INSULATION TRENDS

In addition to new materials, other factors affecting insulation and its application have appeared in recent years. New concepts of construction and increasing demands for higher power output have a definite effect on insulation.

Higher Voltage Machines—The economics of generating electrical energy have dictated larger and larger con-

centrations of power in a single unit. Machine designs have now reached the physical size where increased ratings must be achieved by higher operating voltages. This imposes newer and more difficult problems on the insulation designer. Fortunately, new materials already developed for machines in the 15-kv insulation class, such as Thermalastic insulation, are readily adaptable to the higher voltages. The high dielectric strength of this insulation provides protection and reliability without excessive insulating wall thickness. Many machines are being built for at least 20 kv, and several for 24 kv (rated at 250,000 kw). Machines with voltage ratings up to 30 kv are in sight, and several studies are being made toward higher voltages.

Inner Cooling—Inner cooling of high-voltage generator coils is a major advance in cooling techniques, and requires but minimum changes in insulation design and manufacturing methods. In most respects insulation for inner-cooled stator coils conforms to the best practices on conventional machines. Conductor strands are individually glass-covered. Turn insulation is no problem, as these large generators employ single-turn half coils. Thermalastic insulation employing solventless-resin-impregnated mica tape provides the insulation ground wall. The outer binder is a lapped fiber-glass tape, applied before the resin impregnation of the ground wall. It is, therefore, solidly bonded thereto.

One new element of the inner-cooled stator coils requires insulation, namely, the metal tubes that carry cooling gas within the stator coils. These tubes are placed between two halves of the transposed conductor strands. The outside of these metal tubes, therefore, must be electrically insulated from the conductor strands, although they are in intimate thermal contact. The fiber-glass covering on the strands is supplemented by wrapping the individual gas-conducting metal tube with a fiber-glass tape. Thus, each tube is individually insulated from the adjacent tubes and each of the strands of conductor with the equivalent of conventional strand insulation. The metal tubes assume the voltage level of the adjacent conductors by a capacitive coupling, and therefore do not require major insulation. The relatively light electrical insulation between vent tubes and conductors offers low thermal resistance to heat flow from the conductor into the cooling gas. From this it is evident that within the slot and in the main part of the end windings the insulation on an inner-cooled generator does not differ from normal practice on conventional machines.

Only at points where cooling gas enters and leaves the stator core do new insulating problems arise. On the inner-cooled stator coils the ventilation is straight through the coils from end to end, which simplifies insulation problems. At the extreme ends of half coils, where the slot-to-slot connection must be made, a new insulation problem was created by the existence of the ventilating openings through the main ground insulation. At the extreme ends of the half coils the gas-conducting tubes must leave the conductor. The conductors and coils are connected to each other in a conventional manner and the cooling tubes must have access to cooling gas. The opening in the ground wall for entrance of cooling gas to the tubes changes the insulation from a dielectric barrier to a creepage surface at that point. Exhaustive studies have demonstrated the adequacy of the creepage spacing and striking distance allowances on these end windings. Modern windings employed by Westinghouse are designed to be corona-free under operating conditions and under conditions of impulse within the

limits of their surge-protection equipment. Considering that in a high-voltage winding of this type more than 90 per cent of the voltage of the copper appears on the surface of the insulation in the end winding, conventional windings that have complete barrier insulation on the end turns are remarkably corona-free. Reasonable additions to the creepage distances and to the striking distances give adequate margin of safety at the point where the metal tubes leave the conductor. The addition of a molded cap of silicone rubber at this point gives added safety, although the design is such that this addition need not be depended upon.

IN THE FUTURE

Although much progress has been made in insulation development in the past decade, the accomplishments also emphasize the potentialities that remain. For example, in the large-machine field, mica is not likely to be supplanted as the basic ground insulation within the foreseeable future; however, as Thermalastic insulation proves, there may well be better ways to utilize it in combination with other materials. The chemical field has already produced many new insulating materials, but the surface seems hardly to have been scratched.

The improvements to come can take many avenues. Machine designers would like to use less space for insulation, to have higher dielectric strength, lower dielectric losses, greater voltage endurance, longer thermal life, higher operating voltages and temperatures, reduced variability, improved resistance to contamination and damage, greater reliability, and a whole host of other improvements.

WAVE GEOMETRY FOR LONGITUDINAL STRENGTH

LCDR. S. R. HELLER, JR., USN

THE AUTHOR

was born in Norfolk, Va., in 1920. He was graduated from the University of Michigan with the degrees of B.S.E., in Naval Architecture and Marine Engineering and in Mathematics. Following graduation he was employed by the New York Shipbuilding Corporation. On entrance in the U. S. Navy in 1942 he was ordered to the Norfolk Naval Shipyard and assigned to carrier construction. After World War II he was ordered to the Massachusetts Institute of Technology for postgraduate instruction resulting in the degrees of Naval Engineer (1950) and Doctor of Science in Naval Architecture (1951). Since that time he has been designated for Engineering Duty only and assigned as Assistant for Aircraft Carriers, Hull Design Branch, Bureau of Ships.

INTRODUCTION

From the time man first began to build ships, he has been faced with the problem of providing adequate strength for his floating structures. So long as ships were relatively small and constructed of wood, the problem of providing sufficient strength for ships was not acute. Actually, the ship designer did little more than copy the last successful ship. When, however, iron began to be used as a shipbuilding material in the middle of the Nineteenth Century, the naval architect was confronted not only with a new material with new properties, but also with the fact that the additional strength of the new material permitted the use of members of vastly reduced cross-section—and he had no past practice to guide him.

The prominent naval architects of the time turned the powerful tools of mathematics and mechanics to the job of developing a satisfactory criterion of strength. These men strove mightily toward a solution—and not without rewards . They succeeded, by dint of perseverance, in developing a standard calculation which has served satisfactorily even to the present time. What purpose, then, will another paper rehashing this tested procedure serve?

The answer to this question is, in truth, an elusive one. Certainly a change in the traditional calculation is not expected to be made without careful and searching examination. A mere search of past history, while of academic interest to the thoughtful technician, is not, in itself, of intrinsic

value. If, however, past history is carefully studied in consort with recent information which has hitherto been unavailable, some inconsistencies in the standard calculation may be ferreted out and the way to avoid them developed. The purpose of this paper, therefore, is fourfold:

a. To trace the historical development of the standard longitudinal strength calculation;

b. To point out the inconsistencies in this calculation;

c. To suggest remedies to the inconsistencies; and

d. To provoke the careful and searching examination so necessary to accepting a change.

DEVELOPMENT OF A STANDARD

In the very first issue (1860) of its *Transactions,* the *Institutions of Naval Architects,* the oldest technical society dealing with the shipbuilding profession, published several papers on "the strength of iron ships." In one of these, Fairbarn (1)* proposed the criterion of considering ships grounded either at mid-length or on supports at each end. Even with the sad launching experience of *Northumberland,* where the ship had stuck on the ways for several weeks with about one-eighth the ship overhanging the way ends, in their minds, the naval architects of that day rejected that proposal as totally unrealistic. It was not that they considered grounding impossible, for that type of accident had occurred within the memory of all; but rather that it had always happened under the most adverse combinations of heavy weather and inept seamanship. Then too, none of the ship designers could convince themselves that grounding could occur on concentrated supports with no buoyancy present to relieve the load. Their experience had been contrary to these assumptions. Finally, a few calculations proved that, almost without exception, all ships that had been severely buffetted by wind and wave and yet survived would have failed completely if subjected to Fairbarn's assumed conditions.

With the extreme condition of grounding discarded, new hypotheses were sought. Should a routine examination of ship in still water be used? Even the most naive naval architect realized that this procedure was inadequate, for he had seen ships subjected to the random action of wind and wave. Quite naturally, they turned to extreme yet more common occurrences for design methods. Reed, in a memorable treatise (2), proposed that the ship be supported by waves. Except for a few minor changes, the procedure proposed by Reed is used even today and is strikingly similar to that outlined in the Appendix.

Although the designers had now established the conditions under which strength calculations would be performed, the wave geometry to be used still required solution. Froude (3) had already demonstrated that ocean waves could be closely represented by the trochoid.† The desirable properties of a trochoid—close representation of actual waves, mathematical definition, and ease of geometric construction—led to its widespread adoption in a relatively short time.

The choice of the trochoid only partially answered the questions of wave geometry. Although the wave profile was settled, the choice of proportions still remained. Reed had postulated,

*Numbers in parentheses refer to Bibliography.

†A trochoid is a curve generated by a point in a circle which rolls along a straight line.

and John (4) echoed, that, for a given height of wave of trochoidal profile, a wave of length equal to the ship's length would produce the maximum bending moment. These statements were accepted and, thus, the wave length was standardized. Only the wave height remained to be fixed.

Many reports of observations of waves were studied to see what light could be shed on the remaining wave dimension. Unfortunately, instruments for the accurate determination of wave dimensions were not then available. The only source of raw data was the seafaring observer, but his penchant for exaggeration cast considerable doubt on the value of his observations. Therefore, the choice of wave height was dependent upon the whims and prejudices of the man who evaluated the data reported. Out of the many series of observations made and reported during the latter part of the Nineteenth Century, one, that by Lieutenant Paris of the French Navy, which was carefully and meticulously recorded during several cruises over the most heavily traveled trade routes, stands out as probably the most reliable. White (5) reports the following table based on these observations:

TABLE I

Wave Dimensions (according to Paris)

Length of Waves (Feet)	No. of OBS.	Length/Height Min.	Ave.	Max.
Less than 100 ..	11	5	17	30
100-200	55	9	20	40
200-300	44	10	25	40
300-400	36	17	27	40
400-500	17	15	24	40
500-650	16	17	23	40

White also reported on typical strength calculations performed during that period and cited the variation in the ratio of length to height of from 15 to 20 for warships and 20 to 30 for merchant ships, Apparently, however, based on Paris' observations, White recommended that the ratio be standardized at 20 for lengths less than 300 feet and at 25 for lengths greater than 300 feet.

White's recommendations were used extensively until the turn of the Twentieth Century at which time Biles (6) recommended a standard wave height of one-twentieth the length. This recommendation was based on re-analysis of Paris' data plus additional information obtained from more recent observations. In substantiation of his recommendation Biles quotes Paris as stating that the average dimensions of what sailors call a high sea are 348 feet in length and 16.5 feet in height and the corresponding dimensions of a very high sea are 485 feet and 25.5 feet. But Biles continues; "We may, therefore, infer that regular series of waves 500 feet and upwards are not very frequently met by ships, but, *for purposes of comparison,** we may assume that the stresses which would be brought upon a vessel when poised on a wave of her own length and a height one-twentieth of the length, ought to be provided for in the disposition of material in the structure."

And thus a standard was born: the bending moment should be calculated for the upright ship statically poised on a trochoidal wave of its own length and of height equal to one-twentieth of the wave length; pressure and hence buoyancy should be assumed to be directly proportional to depth below the wave surface; the midpoint of the wave (either crest or trough) should be aligned with the midpoint of the ship; the ship should be trimmed on the wave so that the center of gravity and center of buoyancy are in vertical alignment.

*Italics by this author.

RECENT DEVELOPMENTS

Since Biles' recommendations to standardize wave proportions and methods of calculations were accepted, there has been considerable further study on all parts of the standardized procedure. This is only natural and proper, for it is axiomatic that the successful structural designer must begin with a knowledge of the loads to which his structure is subjected. Because these studies have not generally been evaluated jointly, but instead examined separately, they are presented at this time in a genuine effort to determine their effect on the standard procedure.

Wave Proportions.—It has long been recognized that as wave length increases the ratio of height to length decreases. In fact, White's recommended standards included it. Even Biles, to whom we are indebted for the existing standard, noted this fact, but preferred to overlook it for the sake of uniformity of calculation. No less an authority on ship structure than Hovgaard recognized it and in (7) recommended that the standard wave should be used for ships up to 700 feet in length and, for ships longer than 700 feet, the wave to be used should be 700 feet long by 35 feet high.

Although many studies were conducted by trained observers and almost all such studies were published, little effort was expended to codify them. As an example, Figure 1 plots lengths and heights of great sea waves reported by most of the European countries and the United States for the period of October, 1908 to May, 1913. This compilation was made by the Hydrographic Office of the U. S. Navy. No attempt was made to correlate these data until shortly after World War II when the Bureau of Ships set up a Committee on Longitudinal Strength under the chairmanship of L. W. Ferris. This committee dug deeply into past records and unearthed a tremendous amount of data. The curves for the theoretical limit of steepness $L/H=7$; the standard wave, $L/H=20$; and the line of greatest density were added by that committee.

Cornish (8) reported the results of observations over a long period of time and included sources of errors and their magnitude. This meticulous care lends considerable credence to the Cornish data.
From these data, J. C. Niedermair of the Bureau of Ships, in an unpublished memorandum, evolved the empirical relationship: $H=1.08\sqrt{L}$. This expression may be transformed into: $H/L=1.08/\sqrt{L}$, which has the desirable property of having wave steepness (H/L) decrease with increasing length. Cornish, in a later work (9) reported additional data and revised his previous conclusions. An analysis of this work produces a new empirical formula: $H=1.35\sqrt{L}$, which, since it is in the same form as Niedermair's, has the same properties. At about the same time, Marmer (10) published a slightly different empirical equation covering Zimmermann's data:

$$L=7.15H^{4/3}.$$

In the period just prior to World War II, some full scale structural tests on ships at sea were made which also included wave measurements. Bridges (11) and Schnadel (12) both presented new wave data. Although Schnadel was more concerned with actual structural performance than with wave data, the presence on board of two such distinguished wave physicists as Weinblum and Horn together with superlative optical equipment and electric measuring devices certainly vouches for the accuracy and validity of the data.

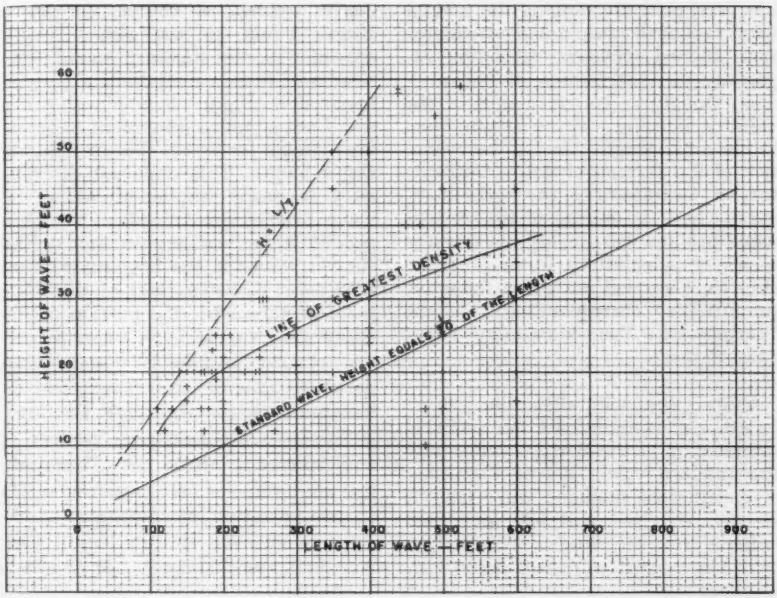

Fig. 1

Since the end of World War II, the Scripps Institution of Oceanography have made available two new digests of observations, (13) and (14). These references are of particular interest since they have been prepared by trained oceanographers and from data taken with equipment designed especially for that purpose. Although it is admitted that these data are not the ultimate, they must be considered as representative of the finest now available. Quite recently, wave measurements were taken during the full scale structural tests at sea on *Ocean Vulcan*. This information together with other observed wave data is presented by Turnbull (15) and an envelope curve drawn. The combined data from (8) through (15) are shown in Figure 2.

Wave Profile.—Since the historic paper by Froude (3) the science of photography has developed amazingly. No longer are oceanographers able to approximate ocean waves by trochoids alone. Stereophotogrammetric films show that waves driven by wind have different slopes on the windward and leeward sides. These same films show that the actual profile of storm waves are nearly cycloidal whereas waves moving on their own momentum are very nearly trochoidal. In a recent publication (16), the Hydrographic Office shows several examples of these pictures and, although they call attention to the variation of the profile from a trochoid, no substitute profile is offered.

Length of Wave.—Little attention

has been paid to changing the lengths from that of the ship under consideration. Indeed, physical reasoning regarding the distribution of buoyancy was enough to convince one of the validity of using a wave length equal to the ship's length. During the operation of the Bureau of Ships' Committee on Longitudinal Strength, however, when the merits of the various wave profiles were being discussed, a series of calculations for a proposed ship were carried out using the wave proportions corresponding to the "Scripps One Year Maximum" curve (see Figure 2).

Quite conicidentally the ship's length corresponded to the point of intersection of the Scripps curve with the standard wave, 520 feet. The series of calculations included wave lengths of 350, 400, 450 and 520 feet with heights corresponding to the Scripps curve (which, of course, for wave length equal to the ship's length agreed with the standard wave). The results of these calculations are summarized in Figure 3 which shows a small but significant increase in bending moment for waves shorter than the ship's length. This apparent discrepancy is easily explained when the wave profiles are traced on the ship profile. With the ship positioned on the shorter waves in the hogging position (midpoint of wave crest at the midpoint of the ship), the portion of the additional waves, both forward and aft, approach parallelism with the ship profile at its ends and, hence, add no buoyancy there. Only for the very shortest wave considered, 350 feet, is any buoyancy added aft. Therefore, this condition for calculation amounts to concentration of buoyancy amidships in an even shorter length than

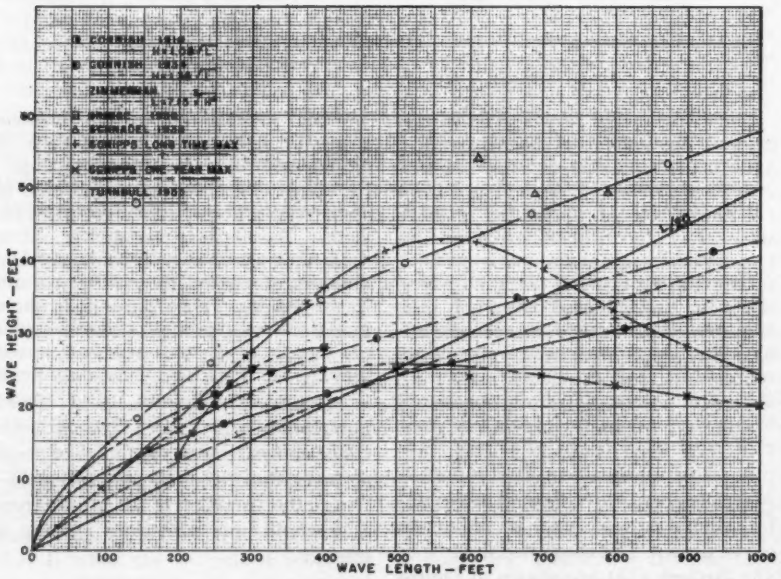

Fig. 2

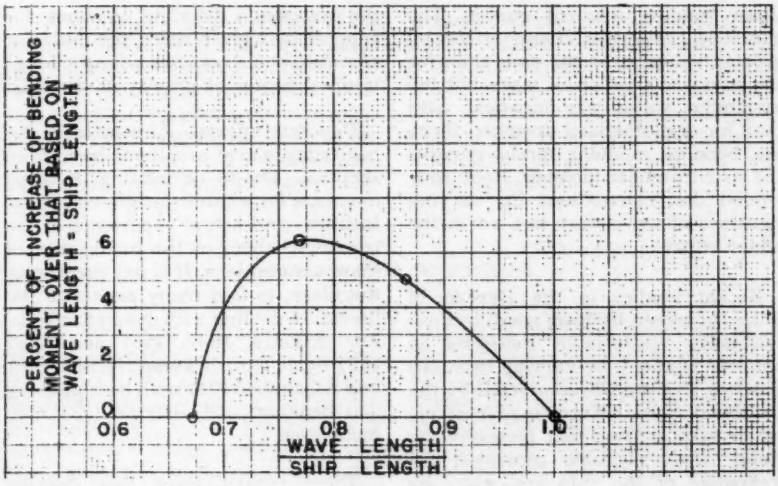

Fig. 3

would be the standard wave. Hence, a greater bending moment is realized.

Although the results shown in Figure 3 were obtained from a series of calculations using the Scripps curve, the same phenomenon has since been observed for other wave proportions. The necessary and essential condition is that the portions of additional waves do not add buoyancy at the ends of the ship.

Wave Pressure.—One of the basic assumptions whereby the standard longitudinal strength calculation is performed is that pressure, and hence buoyancy, is directly proportional to depth below the wave surface. Smith (17) showed that pressure in the wave is *not* proportional to depth below the surface. By taking accurate account of pressures according to the trochoidal wave theory, the supporting force is shown to be decreased in the crest and increased in the trough. Accordingly, buoyancy is distributed somewhat more evenly and, therefore, both hogging (wave crest amidships) and sagging (wave trough amidships) bending moments are decreased somewhat. The "Smith correction" is based on the assumption that pressure in the wave is not affected by the pressure of the ship.

Location of Wave.—Two conditions are normally calculated: one hogging with the wave crest amidships which puts the deck in tension and the bottom in compression; the other, sagging, with the wave trough amidships which puts the deck in compression and the bottom in tension. It has long been customary to position the midpoint of the ship at the midpoint of the wave for these calculations.

Robb (18) made a study for a typical merchant ship in which he varied the location of the midpoint of the wave along the length of the ship. As a result of these calculations, Robb drew a series of bending moment curves each of which corresponded to a different location of wave. It was then possible to draw a curve enveloping all

these bending moment curves. The envelope curve was characterized by greater values near the ends than for the standard position of wave but the maximum value was *identical* with that for the standard position. Since the bending moment rarely governs the structure near the ends, Robb concluded that calculations for varying locations of wave were not worth the added effort.

Recent studies in the Bureau of Ships, however, indicate small but occasionally appreciable increases in bending moment for varying locations of wave. The studies conducted by the Bureau of Ships differed in at least one major respect from that presented by Robb. Whereas Robb separated the midpoints of the ship and wave by relatively large fractions of the ship's length, the Bureau of Ships separated them by at most 5 percent of the length. Figure 4 presents the results of these studies for a destroyer and an aircraft carrier. These curves are typical of the studies and show clearly that, to obtain the maximum bending moment for support by a given wave, the midpoint of wave should coincide with the longitudinal center of gravity of the ship.

Dynamic effects.—Almost from the beginning, naval architects have been skeptical about calculating bending moments for a static upright condition. Intuition and actual experience at sea convinced them of the artificiality of these assumptions. It is not surprising, therefore, to find many papers in the literature dealing with dynamic effects. For instance, Robb (18) and Read (19) dealt with heaving; Kriloff (20) and Alexander (21) with both pitching and heaving; and Jenkins (22) with inclination.

These studies show that heaving into a wave increases the bending moment somewhat whereas heaving out of a wave decreases the bending moment slightly. These studies also show that the effect of heaving into a crest is less than that of heaving into a trough. Pitching is shown to affect the

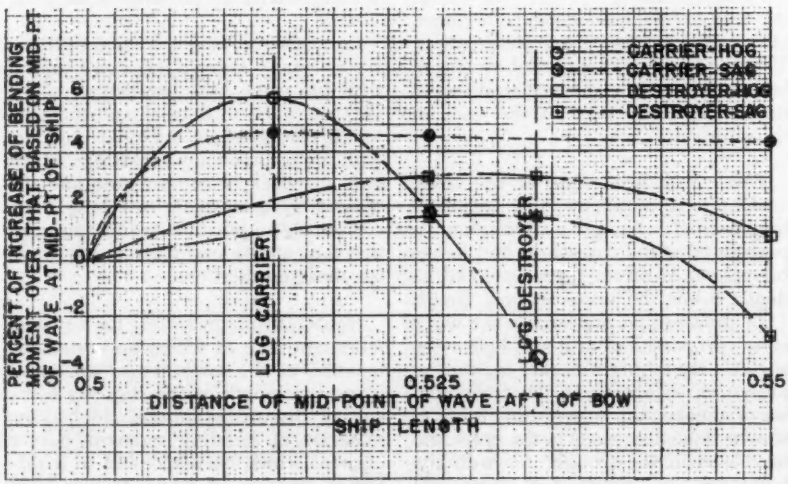

Fig. 4

bending moments near the ends of the ship primarily. But, as has been stated previously, the bending moment near the ends rarely governs structural design there. Although the effect of inclination has no bearing on wave structure or geometry, it is included here for completeness. Jenkins showed that stresses (not necessarily bending moment) increase with increasing angle of inclination up to about 30 degrees where it passes through a maximum. The increase in stress approaches 20 percent and is largely attributable to diminution of section modulus with the ship inclined.

EVALUATION OF REFINEMENTS

The foregoing discussion of the effect of changes to the standard procedure for calculating bending moments has pointed out numerous inconsistencies in the procedure. In each instance it has been shown that the assumption corresponding to the point in question leaves room for skepticism.

First, the wave proportions are shown to be inconsistent with observations made with modern and more accurate instruments than were available at the time the standard procedure was proposed and accepted. Only a talented oceanographer could recommend which of the curves of Figure 2 is the best. A naval architect, however, can readily see that all the curves of Figure 2 have one thing in common: the ratio of height to length (wave steepness) decreases as length increases. Certainly, the standard wave is suspect if we really want to determine *actual* not *comparative* stresses.

Second, it is shown that storm waves can not be represented accurately by trochoids. Again we must rely on the oceanographers. The naval architect, however, can perform his calculations based on a trochoidal profile and allow margin for the differences by applying a safety factor or reducing his allowable stress. Such a procedure could be followed until the oceanographers recommend a wave profile.

Third, it has been shown that small but significant increases in bending moment can be obtained with wave lengths shorter than the ship's length provided that the portions of the additional waves do not add buoyancy at the ends of the ship. Hence, equality of ship length and wave length does not necessarily produce the worst case, maximum bending moment. Nor is it necessarily a realistic condition.

Fourth, Smith has shown that, for a trochoidal wave, pressure is not directly proportional to depth below the surface. Seldom have calculations been prepared using the "Smith correction." The usual reasons for neglecting this phase are that the standard calculation is conservative (the "Smith correction" reduces bending moments) and the precision gained is not worth the labor expended. Perhaps these arguments are valid, but certainly, if actual stresses are desired, simplifying assumptions must stand on their own merits.

Fifth, it has been shown that small absolute increases in bending moment can be obtained by locating the ship so that its longitudinal center of gravity coincides with the midpoint of the wave. Extra effort can not be claimed since no additional calculations are required. Nor can lack of information become the bugaboo since the ship's longitudinal center of gravity is a nec-

essary item of knowledge to obtain an equilibrium condition.

Sixth, correction for dynamic factors has been shown to be theoretically possible although admittedly complex in execution. Traditionally, these corrections have been neglected on the grounds that the effort involved is not worth the precision, that there is no experimental verification of the theory, and that the reduction in bending moment due to the "Smith correction" offsets the cumulative increases due to the dynamic effects. It must be admitted that there is a modicum of truth in these arguments. One fact, however, shines through undiminished: similar corrections are customarily applied in the design of structures other than ships regardless of the complexity.

In considering these studies and the modifications to the standard procedure that they suggest, one must weigh the several factors carefully. This, of course, brings to mind the question: Why do we make longitudinal strength calculations? If the answer is, as it has often been said, merely to compare the bending moment calculated for one ship with that calculated, on the same basis, for another similar ship with a successful record, then the necessity for this complex computing procedure is questionable. Certainly, with the tremendous amount of accumulated data, it should be possible to correlate this information for the various types of ships and produce an empirical equation relating bending moment to the principal dimensions of the ship. Thus, for the majority of ships, there would be no need to expend manpower on the lengthy calculations outlined in the Appendix, but rather choose the bending moment on the basis of this empirical relationship. Naturally, for a new type ship for which no background information exists or for a ship of unusual form or load conditions, the lengthy calculation could and should be used.

If, however, the answer to the question is that we are attempting to actually determine the stresses to which the ship is subjected at sea, then it follows that we should redouble our efforts to find not only satisfactory wave profile and proportions but also refinements for our calculations to allow for the dynamic effects plus the effects of wave pressure, length, location, and so forth. The refinements of the basic calculations may be obtained either by more complex calculations or experimentally from actual measurements at sea. Naturally, the latter option is the more attractive to the ship designer since it would not only eliminate extra time and manpower in the design office but would also offer a factual, not theoretical, background. In either case, however, if actual stresses are desired, the basic calculation should be performed in such a way that the conditions assumed simulate, as closely as possible, the worst actual conditions at sea.

Although the record with regard to structural failures which are attributable to insufficient longitudinal strength is good, the record of extraneous structural material used is undetermined. Without refined calculations which can be expected to predict actual stresses with a high degree of precision, refinement of structure, particularly elimination of material which does not carry its proportionate share of the load, is impossible.

CONCLUSION

The historical development of the standard logitudinal strength calculation has been traced; its inconsistencies have been highlighted; remedial action for these inconsistencies has been suggested. For the most part,

these things are not new. They have largely been presented previously—and with indifferent success. Almost without exception, the proponents of the existing standard have plaintively wailed that the various proposals have improved accuracy by the addition of disproportionate complexity and effort. These same proponents bemoan the fact that deviation from the standard would scrap the vast amount of data accumulated over a long period of time. At bottom, then, the adherents to the present standard are content to let ship structure be designed on a comparative basis.

In retrospect, it appears that the standard longitudinal strength calculation has achieved immortality. It is as sacred to its devotees as the Kaaba to Mohammedans. It is as unchanging as the course of the stars. So sacrosanct has it become that the neophyte naval architect cannot be ordained without paying obeisance to it by performing the ritualistic calculation. And to what avail? The sheets are carefully bound together and consigned to some obscure pigeonhole to gather dust along with others like it—for these calculations predict no actual stress.

As Reed (2) so ably points out, conditions differ with the passage of time. What may have been perfectly satisfactory in 1871 may not necessarily be acceptable today. The shibboleth of "uniformity for sake of comparison" must be examined with the same careful searching as the proposed change. Change for change's sake is as puerile as uniformity for uniformity's sake. What is really needed is an intensive research program designed to furnish proper wave profile and proportions, an improved calculation procedure, plus refinements, all of which are aimed at predicting actual stresses.

ACKNOWLEDGMENTS

It would be selfish, indeed, not to express the author's gratitude and indebtedness to those who have labored behind the scenes to make this paper a success. Although many persons have contributed their time and knowledge in the preparation of this article, special thanks must be paid to: Mr. F. G. Corkum of the Hull Design Branch of the Bureau of Ships for making available the files and background information of a quarter century, and to Mr. A. M. Johnson of the Structure and Hull Form Section of the Hull Design Branch of the Bureau of Ships without whose counsel, kindness and stimulus this paper would never have been prepared.

APPENDIX

Procedure for Performing Longitudinal Strength Calculations*

1. *Tabulate longitudinal distribution of weight.*

A basic weight curve should be drawn to represent the longitudinal weight distribution of the ship. Normally, it is satisfactory to divide the ship's length into 20 equal segments and use a uniform weight distribution over each segment. The total weight and the longitudinal center of gravity of the simplified weight curve must coincide with the corresponding weight and center from the basic weight data.

2. *Delineate the wave profile.*

The wave profile is trochoidal. The length of the wave is equal to the ship's length. The wave height, according to the current standard, is equal to 1/20 of the length.

3. *Balance the ship on the wave.*

The wave is superposed on the ship with the highest point of the crest amidships for the hogging condition or the lowest point of the trough amidships for the sagging condition. A trial buoyancy calculation is made to determine the total buoyancy and the longitudinal center of buoyancy. Similar trial calculations are continued with the wave moved up or down or trimmed forward or aft until a position is found where the buoyancy equals weight and the longitudinal centers of buoyancy or weight coincide.

4. *Tabulate buoyancy.*

When the final position of the ship on the wave is determined, a precise buoyancy curve is plotted. From this curve are derived the buoyant forces acting on each segment of the length.

At this point, the ship can be analyzed as a "free-free" beam; that is,a beam the ends of which are not supported and, hence, can not be subjected to either vertical shearing force or bending moment.

5. *Determine the loads.*

At each of the segments the effective load is the algebraic sum of weight and buoyancy, considering weight positive and buoyancy negative. The load on each segment is assumed to act at the center of the segment.

*From the standardized procedure used in the Bureau of Ships. This procedure was developed by the aforementioned Committee on Longitudinal Strength.

6. *Determine the shearing force.*

The vertical shearing force acting on any section is determined by arithmetical integration of the loads, starting from either end. If the ship has been accurately balanced on the wave, the shearing force will become zero after the integration has been carried through the full length of the ship. In any case, the error of closure should not exceed 0.2 percent of the maximum ordinate of the curve.

7. *Determine the bending moment.*

The bending moment on any section is determined by arithmetical integration of the shearing forces. If the shearing force has been determined accurately, the bending moment will become zero after the integration has been carried through the full length of the ship. In any case, the error of closure should not exceed 0.2 percent of the maximum ordinate of the curve.

Note 1. Graphical or mechanical integration can be used satisfactorily, but arithmetic integration is usually less tedious and is sufficiently accurate.

Note 2. By definition of a "free-free" beam the bending moment and shearing force at the ends are zero. Hence, the warnings in Steps 6 and 7 above.

Note 3. Additional checks may be used for the proper shape of the curves:

a. The curve of shearing force should reach a maximum, pass through zero and reach a minimum.

b. The curve of bending moment should have a point of inflection, reach a maximum (or minimum) and should have a point of inflection respectively for the specific points previously mentioned on the curve of shearing forces.

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A REVIEW OF UNDERGROUND STORAGE AND ITS STRATEGIC APPLICATIONS TO NAVAL INSTALLATIONS

LT. CARROLL V. KROEGER, USNR

THE AUTHOR

started in the gas business in July, 1946, after graduation from the NROTC Unit, the Rice Institute, Houston, Texas. He worked for Conversions & Surveys Inc. as a field adjuster, and later advanced to crew foreman and complaint specialist. He worked on conversion programs for Central Illinois Gas and Electric Company, The Nashville Gas Company, and Washington Gas Light Company. In March, 1949, he graduated from Vanderbilt University with a degree in Mathematics & Physics. He then joined Blackstone Valley Gas and Electric Company, Pawtucket, R. I., as a junior engineer. In December, 1950, he was recalled to active duty by the U. S. Navy and served as Engineering Officer and Administrative Assistant aboard the USS *Capricornus* AKA-57 during the Korean Conflict. In August, 1952, he was released from active duty with the rank of Lieutenant, and joined Central Indiana Gas Company, where he presently holds the position of engineer. He holds a diploma in "Natural Gas Engineering" from Pennsylvania State College Extension, and has completed the course in "American Gas Practice" conducted by Jerome J. Morgan. He is a member of the American Society of Mechanical Engineers, the American Society of Naval Engineers, the American Gas Association, the Indiana Engineering Council, and is a member of the Indiana Committee for Study of the Underground Storage of Petroleum and its products.

The storage of fuel and other petroleum products has always been an important consideration in the operation of naval installations whether located at an operating base supporting forces afloat or air stations serving air units. Recent developments in underground storage offer varied possibilities for application to military installations for safety in the event of enemy attack.

WHAT IS UNDERGROUND STORAGE?

Underground storage is the storage of petroleum or any of its products underground in natural or manmade cavities with little use of steel or other metals. A recent report indicates that private industry has developed ap-

proximately 14,000,000 barrel capacity of underground storage. This development is startling when one considers that the first underground storage project was commenced near Kermit, Texas less than four years ago. The rapid development can be related to the economics of storage of Liquified Petroleum Gases. Above ground storage costs are in the vicinity of $20.00 a barrel for steel storage of liquified petroleum gases. Underground costs range from 50 cents to $5.00 a barrel depending upon the type of storage developed.

Several methods of storage underground have been developed by the petroleum industry and are being utilized today. These may be divided into approximately six categories:

(1) storage in cavities in salt layers.
(2) storage in cavities in salt domes.
(3) storage in mined caverns in impermeable rocks.
(4) storage in the pore spaces of permeable sedimentary rocks.
(5) storage in abandoned mines or tunnels.
(6) storage in permeable rocks below ground-water levels. (Edholm Method)

Storage in salt layers or domes is a remarkably simple process and is the least expensive to develop. Salt layers underlie many parts of the United States and are located in the Permian basin which includes parts of Texas, Oklahoma, Kansas and Mexico; the Michigan Basin which underlies parts of Michigan, Ohio, Pennsylvania, New York, West Virginia and the Great Lakes area. Salt domes are located all along the Gulf Coast and extend as far as 200 miles inland in Texas, Louisiana and parts of Mississippi.

Preparation of a salt layer or dome for storage is accomplished by developing a cavity in the salt. A well is drilled into the deposit, and fresh water is circulated into the hole. The salt is dissolved by the water creating a cavity for storage purposes. The petroleum product is injected and withdrawn through the same well which was used for washing out the cavity. Assuming that all salts are sodium chloride, 36.2 pounds of salt will be dissolved in 100 pounds of fresh water. Fresh water weighs 62.4 pounds per cubic foot or 349 pounds per barrel. If the specific gravity of rock salt is 2.17

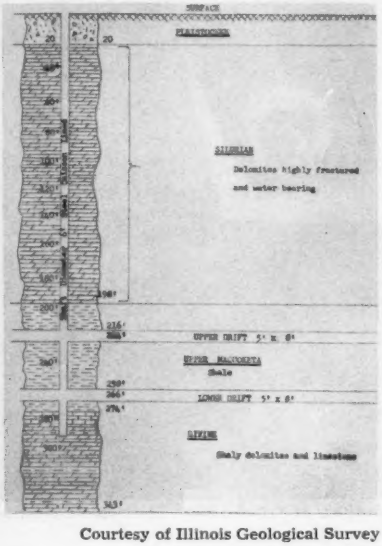
$$2.17 \times 62.4 = \frac{135 \text{/cubic foot}}{3} = 758 \text{ lb. of NaCl/bbl. storage}$$

Therefore: $\frac{36.3}{758} \times \frac{349}{100} = 0.1675$ bbl. storage per bbl. H_2O

or 5.97 barrels of fresh water is required to develop 1 barrel of storage capacity.

Mined caverns are being developed in impermeable rocks in areas where salt formations do not exist. There are many regions which have shallow formations which are satisfactory from a geological standpoint for underground storage purposes. Among these favorable formations are Cherty Limestone, Compact Limestone, Calcareous Shale, Chalk, Siltstone, Anhydrite,

Vertical Geologic Section at Site of Phillips Petroleum Co. Underground Propane Storage, Kankakee, Illinois



Courtesy of Illinois Geological Survey

Fig. 1

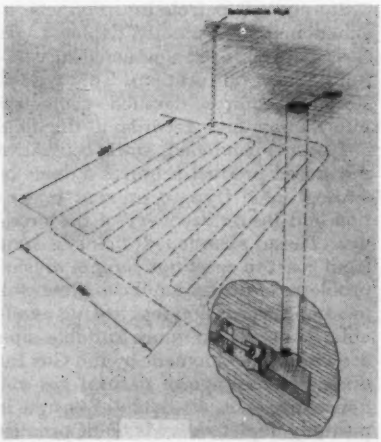
Dolomite, Quartzite, Schist, and Granite. The formation must be thickly-bedded, water free, and non-fractured. Rocks vary in structural strength and the mined cavern must be designed so that the roof and walls are self supporting. Figure 1 gives the lithology of one Illinois project. This cavern is mined out of a dense shale at two levels and has a storage capacity of 260,000 barrels. Development of such a project is a simple mining problem. A shaft is sunk tc a depth of 200 to 400 feet below the surface into a suitable geological formation of impermeable rock. A cavern is blasted out and the material removed by means of a skip hoist, until the required storage volume has been attained. The shaft or drifts may be plugged with a dense concrete and the product to be stored is pumped into the cavern and withdrawn as needed. Figure 2 illustrates the size of the tunnels which are excavated. This photograph was taken 350 feet below the surface in the cavern recently developed by National Petro-Chemical Corporation. The formation mined is a limestone-siltstone sequence and has a storage capacity of 150,000 barrels. Figure 3 is an isometric drawing of the drifts of the storage cavern.

Construction costs of mined caverns vary with the size and depth at which the project is developed. Shaft cost is one of the major items and will require 25 to 50% of the total cost of such a project. A detailed exploration program should be carried out prior to development to determine all conditions which will be encountered once the construction phase commences. Mined cavern storage costs average in the vicinity of $5.00 a barrel. These costs may be less in the future with new methods of shaft excavation now in the development stage.

Storage of petroleum products in abandoned or partially depleted gas reservoirs has been conducted successfully at several locations. This type of storage requires detailed geological information and records if the field has been abandoned, since control of the stored product requires a dome or stratographic trap to prevent migration and insure recovery of the product. These abandoned fields extend from coast to coast but contain myriad problems of utilization if complete well location records and logs are not available. Many of the more suitable sites are under development by the Gas Industry for storage of natural gas and hence are not available. Storage in partially depleted fields holds promise since all the necessary data are available, injection and withdrawal wells

Courtesy of National Petro-Chemical Corporation

Fig. 2



Courtesy of National Petro-Chemical Corporation

Fig. 3

are in place, and there are no well location or plugging problems. Costs of this type of storage are very low since existing facilities can be utilized. Recoveries are low during the first input-withdrawal cycle but there is little or no additional loss after the maximum volume has been attained.

Storage prospects in abandoned mines have been investigated, but the cost of sealing the tunnels to prevent leakage has darkened the economic picture for this method of storage. However one company has succeeded in sealing the ends of an old railroad tunnel in Virginia and storage of liquified petroleum gases has commenced. It was necessary in this case to sandblast the interior surface, and

seal all of the cracks and fissures which existed.

The Edholm method of underground storage was first developed and successfully employed in Sweden. The container may be an underground excavated or natural cavern with the permeable walls or roof below the water table. The presence and pressure of the surrounding ground water is utilized to prevent loss of the stored product. Low vapor pressure products may be stored in an unroofed Edholm container if the liquid level remains below the level of the water table.

WHY STORE UNDERGROUND?

The economic advantage of this type of storage for liquified petroleum gases has already been cited. In addition it is almost competitive with above-ground low-vapor-pressure steel storage. Low-vapor-pressure steel tanks have a capital cost ranging from $1.00 to $2.00 per barrel storage capacity. In addition to this are annual maintenance charges. Storage in salt ranges from 50 cents to over a dollar a barrel. Mined cavern storage may have a capital cost of $10.00 a barrel if the volume is small, or may average from one to two dollars per barrel in million barrel volumes.

Aside from economic factors, underground storage (unlike above ground storage) is not vulnerable to enemy attack. It is inherently safe from industrial accident or sabotage. Visible evidence on the surface of its presence can be easily hidden or camouflaged.

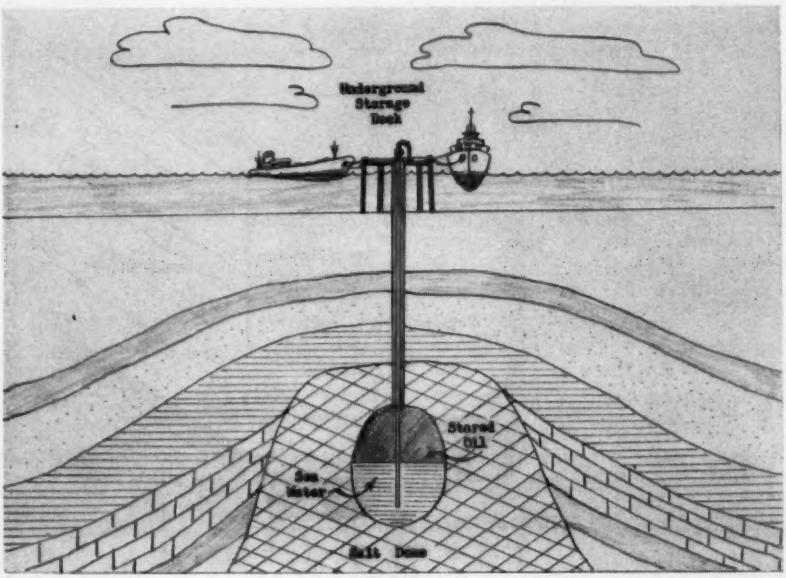


Fig. 4

Little steel is required which enhances its value in wartime. The pressures of the stored product are constant and not affected directly by atmospheric temperatures, and a smaller surface area is required.

Salt domes in the Gulf of Mexico and Mississippi river area have potential for naval storage and refueling stations. Figure 4 depicts an imaginary fueling station in the Gulf of Mexico. A cavity is developed in the salt dome and a permanent storage dock constructed for mooring of vessels and housing the pumping equipment and

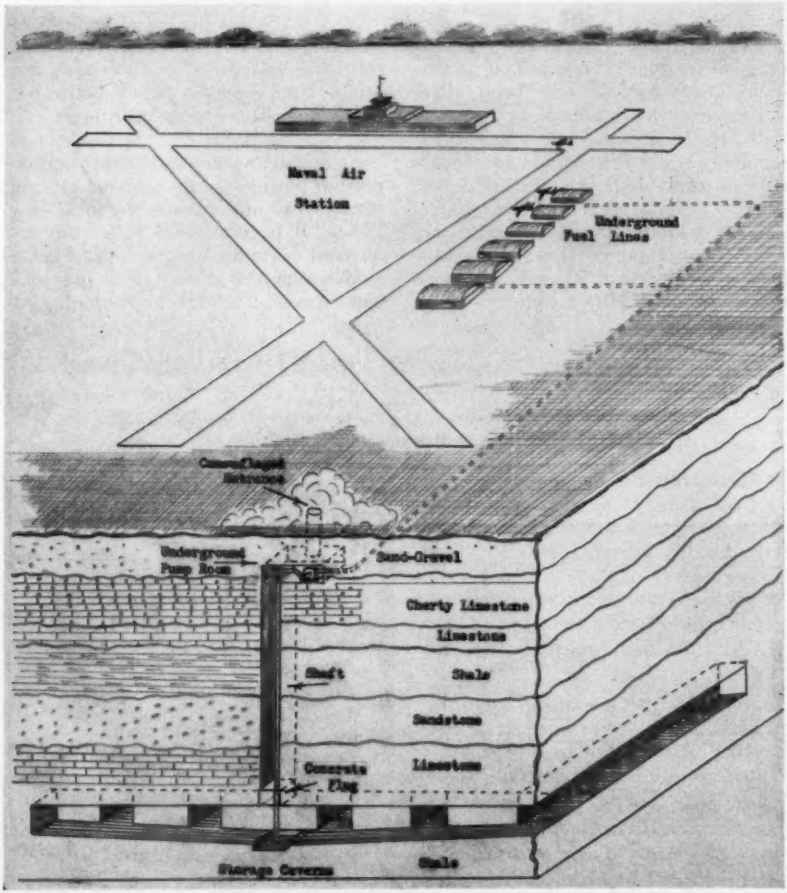


Fig. 5

MILITARY APPLICATIONS

well assembly. The vessel would moor at such installation, and refuel simply by pumping salt water into the cavity. This would cause the fuel to rise through the well casing into the fueling hose and flow into the ships fuel tanks. Such an installation could be designed to project only slightly from the water and could be made to appear as a buoy if desired. The ships pumping equipment could be utilized for the fueling operation in this case.

Figure 5 depicts a cavern storage at a naval air station. This storage would provide safe belowground storage for high test aviation gasoline or jet fuels. With all pipe installed underground such an installation would not be vulnerable to enemy air attack or sabotage by enemy agents. In locations where geological conditions are not suitable for conventional underground methods the Edholm method could be utilized. This would be feasible in the unconsolidated sediments of the Gulf or Atlantic coastal plains. A large caisson would be sunk below ground water level or possibly anchored on the sea bottom. The bottom would be open for the ingress and outgress of water as the stored fuel were injected or withdrawn.

SUMMARY

Storage is moving underground. The rapid development in this field by storage of liquified petroleum gases has established a trend which will expand into the storage of all types of petroleum products. The method has special value for military installations since the future of our nation may depend upon the ability of such installations to survive initial surprise attacks and to launch immediate counter attacks upon the enemy.

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THE FREE-PISTON GAS-GENERATOR TURBINE AS A POWER PLANT FOR SHIP PROPULSION

ACKNOWLEDGEMENT

The article appeared in the June 1954 issue of "The British Motor Ship." It is an abridged version of a paper read at a meeting of the Institute of Marine Engineers by F. A. I. Muntz, Chairman and Managing Director of Alan Muntz & Co., Ltd., and H. Huber, Technical Director of Soc. d'Etudes Mecaniques et Energetiques.

In a gas generator, the whole of the air from the compressor is delivered to the engine cylinder, which is therefore highly supercharged, the large excess of air passing out to the exhaust as scavenge air. The hot exhaust products join with the heated scavenge air and the whole constitutes the "power gas" that is delivered to the turbine. The power gas consists of at least 75% of unburnt air, the remainder being the products of combustion of the fuel.

The overall compression and expansion ratio of the cycle is very high, which is well known to be one of the essentials for high thermal efficiency. The first part of the compression takes place in the compressor cylinder, and the high pressure part in the Diesel cylinder. Similarly, the high pressure part of the expansion takes place in the Diesel cylinder and the low pressure part in the turbine.

With the outward compressing type of gas generator it is necessary to employ stepped piston assemblies having additional pistons of smaller diameter mounted on the outsides of the compressor pistons to provide a cushion. This means that not only are the overall dimensions and weights appreciably greater, but the manufacture is almost certainly more expensive.

The maximum output obtainable from an outward compressing type of gas generator must be less than that obtainable from an inward compressing type, because the inherent greater weight of the moving parts will reduce the speed of oscillation.

Piston oil-cooling, which can be arranged extremely easily in the case of the inward compressing type of gas generator, becomes much more easily withdrawn. These are about the only parts that have to be withdrawn during an overhaul.

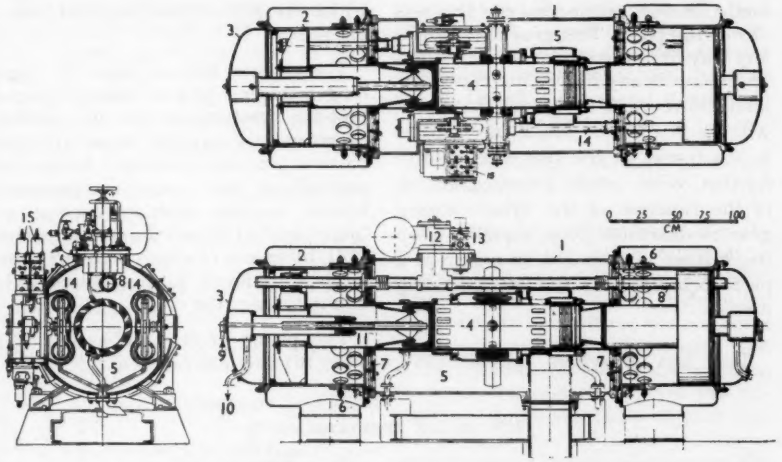

Fig. 1.—Section of GS-34 free-piston gas generator.

1.—Engine casing. 2.—Compressor cylinder. 3.—Cushion head. 4—Engine cylinder. 5—Scavenge air receiver, inside engine casing. 6.—Suction valve. 7.—Delivery valve. 8.—Balance pipe. 9.—Piston cooling oil inlet. 10.—Piston cooling oil outlet. 11.—Gland. 12.—Starting valve. 13.—Cushion control or stabilizer. 14.—Synchronizing mechanism. 15.—Fuel injection pump.

1,250 GAS H.P. GENERATOR TYPE GS-34

Fig. 1 shows sectional drawings of the GS-34 gas generator, which has been developed in France and works on the principle just described. About 60 of these machines have been built and 40 are in operation for electrical generation and rail traction as well as in marine applications.

The leading particulars of the GS-34 are as follows:—

Engine cylinder bore—340 mm., 13.4 in.

Compressor cylinder bore—900 mm., 35.4 in.

Maximum stroke possible—2×550 mm. 2×21.6 in.

Stroke at continuous maximum rating (C.M.R.)—2×443 mm., 2×17.4 in.

Number of oscillations per minute at C.M.R.—570.

Mean piston speed—8.4 m./sec., 1,650 ft./min.

Gas pressure at C.M.R.—3.0 kg/cm.², 42.7 lb. per sq. in. gage.

Gas temperature at C.M.R.—437°C., 819°F.

With ambient temperature 20°C., 68°F.

Gas h.p. at C.M.R.†—1,250 gas h.p.

Specific fuel consumption† — 144 gr./gas h.p. hr., 0.320 lb./gas h.p. hr.

Thermal efficiency into gas†—43% (on lower calorific value).

The one-hour rating is 1,400 gas h.p. at 50 lb. per sq. in. gage.

In addition to the basic components already discussed, the following may be seen in Fig. 1:—

The synchronizing gear (14), which in this case takes the form of a kine-

†*Based on adiabatic expansion.*

matic linkage, connecting the two sets of moving parts. This gear does not in any way limit the stroke of the pistons, and theoretically it does not carry any load. However, it is obvious that there will be in practice small inequalities in the forces on the two ends, due to friction, wear, intake pressure, etc.; it is the function of the synchronizing gear to distribute these equally, keep the pistons in step and so maintain a perfect balance of the reciprocating masses.

The fuel injection pumps (15), which are driven from the synchronizing gear.

The cushion balance pipe (8), running from end to end, which ensures that the pressures in the two cushion cylinders are always equal. To the balance pipe are connected the device controlling the cushion pressure, known as the cushion control or "stabilizer" (13), and the starting valve (12), by means of which high-pressure air is introduced to the cushion cylinders to start the engine.

The piston cooling oil system (9) and (10) can also be seen.

420 GAS H.P. GENERATOR CS-75

A smaller unit known as the CS-75 is at present under development in this country. It is designed on the same general lines as the GS-34, as may be seen from the sectional drawing in Fig. 2.

One difference that may be noted between the GS-34 and the CS-75 is that the synchronizing mechanism of the latter consists of a rack and pinion gear. There is only one fuel injection pump, and it is driven from the pinion shaft.

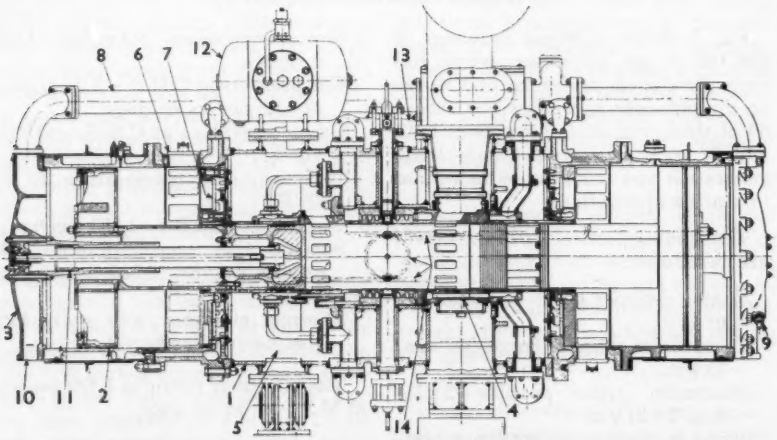

Fig. 2. Section through type CS-75 free-piston gas generator.

1.—Engine casing. 2.—Compressor cylinder. 3.—Cushion head. 4.—Engine cylinder. 5.—Scavenge air receiver, inside engine casing. 6.—Suction valve. 7.—Delivery valve. 8.—Balance pipe. 9.—Pistin cooling oil inlet. 10.—Piston cooling oil outlet. 11.—Gland. 12.—Starting valve 13.—Cushion control or stabilizer. 14.—Synchronizing mechanism.

The prototypes have so far completed about 1,700 hours' running.

Its leading particulars are as follows:—

Engine cylinder bore—7.5 in.
Compressor cylinder bore—20.75 in.
Maximum stroke possible—2×12.75 in.
Stroke at continuous maximum rating (C.M.R.)—2×9.5 in.
Number of oscillations per minute at C.M.R.—1,000.
Mean piston sped—1,580 ft. per min.
Gas pressure at C.M.R.—44½ lb. per sq. in. gage.
Gas temperature at C.M.R.—465°C. (869°F.).
With ambient temperature — 20°C. (68°F.).
Gas h.p. at C.M.R.*—420 h.p.
Specific fuel consumption*—0.325 lb. per gas h.p. hr.
Thermal efficiency into gas* — 42% (on lower calorific value).

The one-hour rating of this unit is 500 gas h.p. at 50 lb. per sq. in. gage working pressure.

The free-piston gas generator is in effect simply an oscillating gas boiler, which produces gas at a temperature of the same order as a modern steam boiler produces steam for use in turbines, but with an efficiency that has so far only been achieved by the compression ignition engine. It is, in fact, a compromise between the Diesel crankshaft engine and the gas turbine. It is, however, one which avoids their respective main disadvantages, namely, the bulk, weight, heavily loaded bearings and torque reactions associated with marine crankshaft engines, and the high temperatures and bulk associated with gas turbines and heat exchangers.

There is also the very important point that neither the free-piston gas generator nor the complementary turbine, which transforms its "power gas" into shaft horse-power, require any better metals than have been in use in Diesel engines and steam turbines for many years past.

It possesses the following additional advantages:—

A number of gas generators of moderate size can be piped together to supply a turbine of any required power. In this way a very wide range of power can be obtained with one size of gas generator, and this means that it will become possible for the first time to obtain for marine engines the advantages in respect both of first cost and maintenance which go with series production of standardized units. In this connection it is also worth noting that gas generators being so much smaller than corresponding marine Diesel engines, and having no crankshafts, their manufacture can be carried out with tools and lifting equipment of moderate size, such as are available in most machine shops—a very important point in time of war.

Due to the moderate temperatures involved, turbines can be made entirely in ferritic steel; and, of course, with the gas-generator system there is no need for bulky and expensive heat-exchanger equipment.

Due to their light weight and freedom from vibration, both the free-piston gas generators and the complementary turbines are very much easier and cheaper to install than the comparable Diesel engine. In addition, gas generators can, due to their small overall height when installed horizontally, be positioned between decks and, moreover, in any convenient position, since there is no need for them to be in line with the propeller shaft.

Due to the fact that highpressure loads are transmitted directly from the

*Based on adiabatic expansion.

engine pistons to the compressor pistons and that very high supercharging is an inherent feature, the weight of gas-generator machinery is inherently low. In point of fact, the weight of GS-34 and CS-75 gas generator/turbine with reduction gear plants works out approximately as follows:—

GS-34 gas generator with reversing turbine and normal reduction gear —38 lb. per s.h.p.

CS-75 gas generators with epicyclic reverse-reduction gear—22 lb. per s.h.p.

The weight of CS-75 sets is substantially lower than that of the GS-34 sets, not only because the weight per horse-power of the CS-75 gas generator is lower than that of the GS-34, but also because it has been assumed that much lighter reverse-reduction gearing (epicyclic) and auxiliary gear will be used in conjunction with the CS-75 gas generator.

Maintenance cannot, in fact, fail to be both easier and cheaper than for a Diesel engine, for the following reasons:—

Any one gas generator can be stopped without affecting the rest, which means that the ship can continue on its course while the individual gas generator is being dealt with.

It takes only 15 minutes to withdraw the two piston assemblies, for instance to change a piston ring, and this very soon after running at full load; and another 40 minutes to reassemble and get the engine running again.

FUEL CONSUMPTION

It seems probable that the straight free-piston gas generator/turbine engine system will have about the same fuel consumption at full load as the corresponding Diesel engine. The specific fuel consumption curve is fairly flat down to quite low loads: for instance, at 50% of full load the specific consumption would be about 12% higher than at full load, and at 25% of full load it would be about 30% higher. These figures would apply to a plant where several gas generators supply a single turbine. Where there is only one gas generator it is necessary to blow off some of the "power gas" at the powers below about 30% of full load. In such a case, the specific fuel consumption below 30% of full load would be increased.

The inherent high supercharge and large amount of excess air make for good combustion of residual fuels and, in this connection, it has the following additional points in its favor:—

Auxiliary power can be provided via auxiliary turbines taking "power gas" from the main battery of free-piston gas generators.

There is no fear of combustion products contaminating crankcase lubricating oil for the reason that fresh oil alone is supplied by a metering pump to the Diesel and compressor pistons and, in any case, combustion products are blown out with the scavenge air.

There is no risk of vanadium trouble as far as turbine blades are concerned, because the maximum temperature of the free-piston "power gas" is normally less than 500°C.

The output of a gas generator is usually expressed as a "gas horsepower." This is defined as the power available from an adiabatic expansion of the gas down to atmospheric pressure; in other words it is the power that would be obtained if the gas were used in a perfectly efficient turbine ex-

hausting to atmosphere. The gas horse-power is, therefore, the product of the adiabatic heat drop and the mass flow of gas.

The adiabatic heat drop is given by the well-known expression:—

$$i = C_p T_1 \left(1 - (P_2/P_1)^{\gamma^{-1}/\gamma}\right)$$

where i=adiabatic heat drop in heat units per pound of gas.

C_p=specific heat at constant pressure

T_1=gas delivery temperature, absolute

P_1=gas delivery pressure, absolute

P_2=atmospheric pressure, absolute

γ=ratio of specific heats.

In fact, the adiabatic heat drop depends principally upon T_1 and P_1, and the variations in C_p and γ are secondary effects only. The gas delivery temperature obviously depends on the inlet air temperature, to which is added the temperature rise through the gas generator. This temperature rise consists of two elements:—

The temperature rise due to the compression of the air; ideally this is merely the adiabatic temperature rise, but in practice there are always pumping and other losses that heat the air above its adiabatic temperature.

The temperature rise due to the mixing of the air with the exhaust gases; this rise comes about because the air in effect picks up the heat rejected from the engine cylinder (excluding the heat to the coolant); and it varies inversely as the indicated efficiency of the engine cylinder.

It follows from this that the delivery temperature T_1 rises with the delivery pressure P_1, but that apart from this an increase of T_1 is, with one exception, indicative of an increase in gas generator losses. The exception is a reduction in heat loss to the coolant,

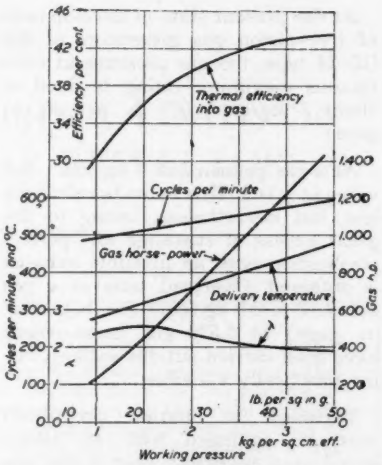

Fig. 3. Curves of type GS-34 machine characteristics plotted against working pressure.

which admittedly would improve the efficiency of the engine but which might have a harmful effect on the life of the liner, pistons and piston rings.

The power delivered by a gas generator is expressed as gas horse-power, by assuming an adiabatic expansion of the gases from the gas generator delivery pressure at atmospheric pressure. This gas horse-power must be multiplied by the efficiency of the turbine/reduction gear in order to obtain the useful shaft horse-power at the reduction gear out-shaft.

The available gas horse-power increases with increasing working pressure, as is shown by Fig. 3, on which are plotted, on a base of working pressure, the following: the power, the gas temperature, the number of strokes per minute, the efficiency into gas, and the quantity λ, which is the ratio of the air trapped in the cylinder to the air theoretically required for complete combustion.

At the present state of development of free-piston gas generators of the GS-34 type, the gas pressure at continuous maximum rating is fixed at about 3 kg/cm.^{2} (43 lb. per sq. in gage).

At a gas pressure of 3 kg./cm.^{2}, the value of λ is 2. This value is relatively low, but nevertheless, owing to the great excess of scavenge air, perfect combustion with an invisible exhaust is obtained. Overload tests at a gas pressure of 3.6 kg./cm.^{2} (51 lb. per sq. in. gage) at 1,530 gas horse-power have been carried out, the exhaust being practically invisible.

Turbines for marine propulsion must be equipped with an astern wheel or a reversing gear if the use of reversible pitch propellers is to be avoided. The sets built so far carry one or two astern wheels on the same rotor as the ahead wheels.

The turbine is provided with a valve with two opposed seating faces, which close the inlet to the astern wheels in its upper position, and in its lower position the inlet to the ahead wheels. This valve is operated by a servo-motor controlled from the operating station by a hydraulic relay. Another relay controls the fuel injection pump.

Before starting the gas generators, the valve is placed at its mid-position. After starting the gas generators, the gas pressure is about 0.4 kg./cm.^{2} (3.7 lb. per sq. in gage); the turbine remains stationary. When the controlling handwheel is turned in the ahead direction, the valve moves upwards and the gas flowing to the astern wheel is throttled, so that the torque of the ahead turbine predominates and the turbine begins to rotate in the ahead direction. The progressive decrease of the passage area towards the astern turbine causes an increase in the gas pressure. During this period of regulation the gas generator is running at minimum delivery.

As soon as the gas passage towards the astern turbine is completely closed the relay between the operating station and the gas generator comes into action and increases the quantity of fuel injected. When the handwheel is rotated further in the ahead direction, the delivery and the gas pressure are increased up to full load.

To reduce power these operations are reversed.

The astern power is controlled by the same handwheel, turned in the opposite direction.

TYPICAL MARINE INSTALLATIONS

A large range of powers can be obtained with the same type of gas generator. For example consider a single gas generator set of 9000 s.h.p. and a 10 gas generator set of 90 s.h.p. The comparison of the weights of these two installations brings out one of the most interesting points of free-piston gas-generator installations, namely, that the weight per horse-power is practically independent of the total power of the installation:—

Power at propeller shaft, h.p.	900	9,000
Weight of gas generators, tons	8.5	85
Weight of turbine and reduction gear, tons	4.0	65
Weight of gas piping, tons	0.5	7
Weight of auxiliaries of of propelling machinery, tons	2.5	15
Total weight, tons	15.5	172
Specific weight, lb. per h.p.	38	42

AERODYNAMIC TORQUE LOADS ON ROTATING RADAR REFLECTORS

BY MELVIN MARK

THE AUTHOR

is in charge of the Applied Mechanics Group, Radar and Communications Division, Raytheon Manufacturing Company, Newton, Mass. He has a Bachelor's and a Master's degree in Mechanical Engineering from the University of Minnesota and a Doctor of Science degree from Harvard. He was associated with the General Electric Company in their Aviation Gas Turbine Division prior to Raytheon. His earlier experience includes teaching positions at North Dakota State, University of Minnesota, and Harvard.

Society Affiliations: A.S.M.E., Sigma Xi, Tau Beta Pi, and Pi Tau Sigma.

(Registered Professional Engineer in Minnesota and Massachusetts.)

Optimum design for the power drive of an exposed marine radar antenna requires a knowledge of the wind loads developed on the reflector, the reflector being that part of the antenna receiving the electromagnetic energy

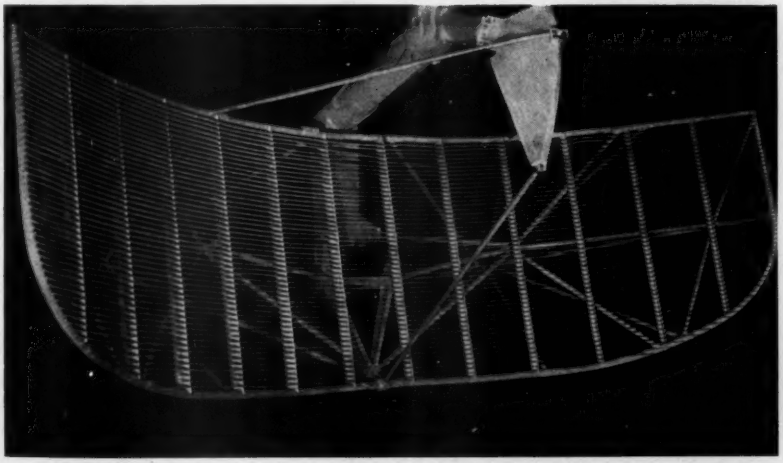

Fig. 1—Photograph of a Single Curvature. Parabolic, Slatted Radar Reflector.

from the power source and radiating it into space in the form of a beam. A slatted type single curvature parobolic reflector is shown in figure 1. In place of the slats, a solid surface or screen might be used. To estimate the torque required to turn the reflector at any rotational speed in a given wind velocity is an exceedingly difficult problem. The aerodynamics are considerably complicated by the configuration. The torque is a function of many variables, among them the type of reflector surface, its size and shape, the position of the axis about which rotation occurs (or pivot position), the rotating speed, and the wind velocity. Examination of the results of some wind tunnel tests on reflectors have shown certain characteristics as described in this article. The information given is general and of a qualitative nature since a large amount of testing would be required before quantitative predictions could be made.

From the standpoint of duty cycle, a plot of torque versus azimuth position (or angle) for a rotating screen or slatted type reflector surface would show major peaks in three azimuth regions—near 90 degrees, between 180 and 270 degrees, and between 270 and 360 degrees. Figure 2 illustrates the type of curves to be expected. (Azimuth angle refers to the angle measured in the direction of rotation to the electro-magnetic beam from its zero position, zero being with the beam directed upstream.) The pivot position, located in the plane of symmetry of the reflector, determines which peaks predominate. When the pivot is near what might be called the optimum position (the pivot position resulting in minimum peak torques), the peaks are approximately equal (curve A in figure 2). On one side of the optimum location, with the reflector placed too far from the pivot, the peak near 90 degrees is the largest (curve B in figure 2). On the opposite side, with the reflector too close to the pivot, the peaks in the regions of 225 and 315 degrees predominate (curve C in figure 2). The slatted and screen surfaces of the same size and shape have similar torque requirements where slats are at zero degrees angle of attack and slat spacing and screen openings are comparable.

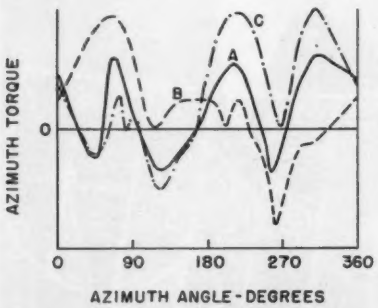

Fig. 2—Typical Torque Curves for Rotating Screen (or Slatted) Reflector. A-Optimum pivot position; B-Reflector placed too far from pivot; C-Reflector too close to pivot.

Tests with a solid reflector showed results quite different from those with the slatted or screen reflectors. The results were erratic in that variations of the torque curve from one cycle to the next could be observed for a given set of conditions. This was not observed for tests with a screen or slatted surface. Some of this may be due to instrumentation and wind tunnel blocking. A larger portion of the discrepancy, however, is probably due to the greater turbulence developed by the rotation of the solid reflector. The solid reflector required peak torques for rotation three to four times higher than a screen or a slatted type of equivalent size and shape. Two major peaks in the torque curves were in the region of 45 and 270 degrees in azimuth.

In a few instances values of maximum torque were obtained for some reflectors rotating under wind load. An attempt was made to correlate these values by means of dimensional analysis in order to get an approximate idea of the relationship between maximum torque, wind velocity, rotating speed and reflector size. Two dimensionless parameters were used.

$(T_{max}/\frac{1}{2}\rho V^2D^2H)$ and (ND/V), and from dimensional homogeneity the relationship written

$$(T_{max}/\frac{1}{2}\rho V^2D^2H) = f(ND/V)$$

where

T_{max} = Peak torque required during a revolution to maintain rotation of the radar reflector.

ρ = Mass density of air.

V = Air velocity upstream of reflector.

D = Span or horizontal distance between ends of reflector.

H = Height or vertical distance from top edge to bottom edge of reflector in plane of symmetry.

N = Rotating speed.

The plot of this available data in the form of equation (1) indicated the functional relationship to be approximately linear in some cases and parabolic in others for reflectors pivoted near their optimum. When off the optimum pivot, no such simple correlation was satisfactory.

To accurately formulate the variation of torque with reflector shape, size, wind velocity, and rotating speed must await the results of considerably more testing. However, from the preceding comments, the importance of the pivot position and reflector surface can be appreciated. A wise selection of pivot position will not only reduce the peak torque required, but improve the duty cycle imposed on the power drive. At present the optimum pivot position cannot be easily predicted, but it can be determined experimentally for a particular reflector. Briefly, the method consists of varying the pivot location by steps and noting the resulting power required to rotate the reflector in an ambient wind. (In the case of an electric drive, measure motor current and voltage, and observe which pivot position minimizes them.) This, in addition to selecting a screen or slatted reflector in place of a solid type wherever possible, will keep aerodynamic torque loads on reflectors to a minimum and optimize the design.

REFERENCE

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A MULTIDISCIPLINARY ANALYSIS OF A PROBLEM OF ENGINEERING COST ESTIMATING: A CASE HISTORY

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The authors are: Part I—K. T. Korn, Management Research Consultant, Akron, Ohio; Part II—Russell L. Ackoff, Operations Research Group, Case Institute of Technology, Cleveland, Ohio; Part III—Anatol Rapoport, Associate Professor of Biomathematics, University of Chicago; Part IV—Harry R. Nara, Assistant Professor, Structural Engineering, Case Institute of Technology; Part V—Marjorie B. Creelman, Department of Psychology, Western Reserve University, Cleveland, Ohio.

I—THE TEAM AND THE PROBLEM

It is my task today to state a problem. Moreover, it is my job to state this problem in a rather unconventional context; that is, in relation to a *multidisciplinary team*. This presents some intrinsic difficulties.

First, because the problem of cost estimating is a part of a number of other problems, namely those of *organization*, in the broader sense, that of *communication* without which organization is inoperative, and finally that of *decision-making*, in the narrower sense.

Second, in considering the problem of engineering cost estimating one should consider the others as problems of higher magnitude which will not be possible in the available time.

Third, the case history which has been chosen as the basis for the statements my colleagues and I are about to make is a part of a *diagnostic* study; in this sense it should not be deduced that it is represented as *research*. The purpose of this study was defined as an attempt to discern problems, identify the reasons behind these problems, and finally to suggest *methods* by which such problems might be solved.

Four, because the problem under discussion was one of many discerned

which was the cooperative effort of a ten-man team of which only five could be with us tonight.

Finally, because this study was conducted in a specific industrial setting, and hence, some generalizations can apply only to this, or very carefully compared situations.

The statement of a *Multidisciplinary Analysis of a Problem of Engineering Cost Estimating,* then, requires a statement relative to the multidisciplinary management research team, and second, a description of the industrial setting in which this team studied one set of circumstances.

In stating the problem, then, I shall attempt to make it clear that the problem of cost estimating which we are to discuss here, while it could definitely be identified as a problem, cannot be considered a self-contained one but rather a component problem within the superordinated ones.

Hence, it would add to clarity if it were possible within the framework of this symposium and its limitations to consider first the problem of *organization,* isolate from it the related one of *communication,* and finally discuss the problem of engineering cost estimating as one form of *decision-making* within the superordinated structures of organization and communication.

Neither the idea nor the practice of systematic inquiry are new. Nor is it a new experience that co-operative effort of a number of people working as a group is more effective than the efforts of one individual. The team, cinsisting of a number of members each trained in a different scientific discipline, obviously, is more effective than one which might be composed of the same number of individuals trained in the same body of knowledge. The advancements of this century supply us with many examples of the "products" of cooperative teams of scientists, technologists, and technicians with competence in many fields. The fact that this is so in the areas of technological, medical, etc., advancements—as is amply demonstrated by the development of the airplane, the jet engine, television, antibiotics, etc.—led to serious consideration and examination of the effectiveness of problem-solving activities in management.

The *policy-maker* in industry and business is faced with two general types of problems. The *technical* type of problem receives today a good deal of attention, thought, top management interest, and—last but not least—financial appropriation. This is rather well documented by the statistics as they are published from time to time; for example, the $64 million annual research budget of one major manufacturer. This is not at all surprising for such research yields new products, new applications of existing products, cost-reducing modifications of products and processes—all of which is quite tangible, and can easily be interpolated into dollars and cents.

The second permissible classification of problems is the *management* problem—the problem which arises as soon as the human element is introduced into the industrial and business process. This type of problem is more difficult to deal with. Its variables are more intricate to measure. Its general nature is more dynamic, more easily given to change. The skills required to deal with such problems are more varied, and usually not so abundant within an organization.

However, the interests of many have been drawn to this type of problem. The psychologist studies the behavior of individuals, and tries to answer

such questions as, "Why do people behave the way they do?" The sociologist is interested in the behavior of groups, and studies such questions as "What motivates this group?" — "How are personal traits, attitudes and beliefs of employees associated with high productivity?" The industrial engineer concerns himself with the design of method and procedures to improve the efficiency of human effort. Others are interested in different phases of this general area. It is not implied here that these efforts are not useful. Quite the contrary! Doubtlessly, each has made its contributions.

What can be learned, however, from the unbiased examination of their successes and failures is that the bodies of knowledge which have been assembled by the different disciplines, all interested in some phase of management is far too complex to be mastered by any one man; but that groups working together as multidisciplinary teams can achieve results superior to those which each could accomplish by itself.

From this sort of thinking was born the idea of multidisciplinary management team research, *MR* for short, as we practice it, and on this basis was built an organization of scientists and technologists with competencies in the branches of science ranging the breadth of the spectrum from logic and pure mathematics to the humanities and behavior sciences. From this considerable pool were drawn the members of the *MR* team which concerned itself with the problems of the company whose case history we have chosen as a background for this discussion. From this ten-man team five are with us representing the fields of management, methodology, communications, engineering, and psychology.

The foundation of the *MR* approach can be found in a few basic concepts:

1. The Effectiveness of the Team is larger than the summation of the Effectiveness of the individuals comprising the team.

2. A Problem cannot be solved unless it is known. This implies that a problem exists on three levels: (a) THE EFFECT LEVEL, or the level on which the symptoms of the problem become evident; (b) THE PROBLEM LEVEL, that is the definition of the area which has deteriorated, and finally, (c) THE CAUSE LEVEL, that is the demonstration of the reasons behind the problem.

This conception of problems makes it easier to see that, first without systematic study one cannot be sure that a problem *is* known; second, that if problem-solving pressure is brought to bear upon its symptoms, the reasons behind it remaining unconsidered, the best that could be achieved is the temporary disappearance of the symptoms which, in turn, will make the reasons behind the problem infinitely more difficult to discern.

3. Diagnosis does not cure. While it is a valid statement to say that problems cannot be solved without diagnosis, diagnosis alone will not provide a remedy. In this sense, it is not the purpose of *MR* to *solve problems* but rather to make problems amenable to systemic attack, and to make *those having the problem more effective problem-solvers themselves.*

4. An Enterprise is an Organism-as-a-Whole. An industrial or commercial enterprise can be likened to a complex, living organism, not at all unlike a biological organism. As the biological organism must function as a whole, as an entity, so must the business organism. Its components must be coordinated to the purposes of the whole. Severed from the whole they become meaningless and often useless. An industrial organism, however, consists of a multitude of individual organisms, etc., and

hence, in its entirety, it is infinitely more complex and more complicated. More complicated not merely to deal with but more complicated to understand. To attempt to solve the problem of—say—"an arm" of such a complicated organism by merely concerning oneself with that limb would preclude the possibility that its disorder might originate in some other part of the organism, for example, in the central nervous system.

5. Management knows its business. We, in *MR* believe that the people who "run" an enterprise know their business. It might be said that they are "experts in the things they do right." They need no one to tell them how to run their own business. What the 'manager,' the policy-maker, needs is assistance in diagnosing difficulties, having his problems stated so that they are susceptible to the scientific approach which has proved to be the most fruitful one yet developed in organized, productive, human endeavor, and the development of methods by which a company's own personnel can solve its problems. In that way the management of a company is helped to become more effective problem-solvers themselves. This is important when we remember that no panacea will ever evolve. There will always be problems, and the responsible people in industrial and business management will always have to deal with problems of management. Thus, a *MR* team sees its function truly as a *con*sultant, not as an *in*sultant.

So much for the philosophy and practice of the multidisciplinary team in management. To set the stage properly it is also necessary to tell you a little about the cooperating company. Above all, the company is a leader in its own field, the design, manufacture, and construction of special-purpose heavy materials handling equipment. It looks back to a history of almost seven decades of successful operation. They are not a large company. About four hundred employees produce in round figures, ten million dollars' worth of annual sales. A sizable part of this is individually designed and constructed. A smaller part makes up a manufacturing program of designed apparatus where merely application modifications are required. In general terms they are in 'good' shape. Their financial position is sound. They discount their bills. Their banking relations are excellent. They make a profit. Their break-even point is high at about 40% of their volume, but it is under control. Their labor relations are satisfactory, and better than those of many other similar companies. Their labor turn-over is 'high' but less than that of others. Their management and technical personnel are competent. There are little fires every once in a while but they are put out quickly. They will flare up somewhere else, and be put out again. Their top management group is composed of capable, foreward-looking, even enlightened men.

They reasoned that it is well for a man to see his 'physician' every once in a long time to reassure himself that "all is well," or to detect the beginnings of illness early enough to deal with them more easily, not to wait for serious illness to strike! Their viewpoint regarding the future might be described as anticipatory of 'harder' time. The present top management guided the company through the depth of the depression. Successfully, as is evidenced by the fact that the company did not merely survive, but it grew. But the memory of the depression days is still vivid in the minds of the 'older' people. Many top positions have been filled since by 'younger' men who do not have the carry-over of the depression experience, and the top people are worried about their ability to meet conditions which might in some ways

resemble those of the thirties. They believe that their company has gone through a period of ten to fifteen years of 'easy' business, and they believe that that will not remain that way. They wanted to find out how ready they were to meet such conditions if and when they would arise. An astute management, indeed!

A *MR* team of nine was composed. Its purpose was specifically not one of providing "cures," but rather a *diagnostic* one. What are the problems? What are the reasons behind the problems? What are the alternative solutions from which one could be selected.

The team was composed of one methodologist, one operations research analyst, one engineer, one industrial psychologist, one sociologist, one clinical psychologist, one market analyst, one biomathematician, and myself.

To these nine was added one employee of the company who was intimately familiar with its operations, personnel, and who enjoyed the confidence of top management.

Our team conceptualized the client company as a *process*. A process is a set of simultaneous and consecutive steps tending toward the attainment of a final state or goal. At each step there may be a set of alternatives among which one eventually becomes the next step of the process. Each step is the result of a decision, that is the selection of one from a set of alternatives. The efficiency of the process can be defined in terms of the contributions which the decisions make toward the likelihood that desired goals will be attained.

This process was studied (1) with respect to the individuals who perform it; (2) with respect to the equipment used in its performance; (3) with respect to the structural and functional organization of the individuals and groups; and finally (4) with respect to the process of decision-making.

By far the most momentous and weighty decision a company of this character must make is the preparation and submittal of bids and quotations. In the majority of cases a firm bid must be submitted before a contract can be obtained. If the bid is too high the contract may not be obtained. If it is obtained, a profit is likely to result. If the bid is too low, the chances that the contract will be obtained are higher—but so are the probabilities of its execution at a loss to the company.

In this sense then, the estimating procedure is a form of decision-making, and an extremely serious one at that. The process of decision-making, however, seems inseparable from that of communication, for the preparation and submittal of an estimate are a form of communication. The preliminary designs of equipments which must precede the estimating and the estimating process itself, are important components of a company's communication process. Communication does not merely concern itself with "making statements," but concerns itself equally with the degree to which statements are understood. Thus, it becomes inseparable from the people who do the communicating, and its effective design becomes a function of the degree of insight into motivational, behavioral, and interactional patterns which exist in a specific setting. This demands insight into the personalities of the individuals and groups comprising the organization.

II—A METHODOLOGIST'S APPROACH

The term "methodologist" may be strange to some of you, and with good reason, for it is a relatively new branch of science. This history of science has consisted in part of a progressive extension of the types of processes which

have been subjected to scientific study. First there were physical processes, then chemical, biological, psychological, and social processes subsequently became susceptible to scientific method. Most recently, the process of scientific research itself has been opened to scientific study. The result is "methodology," the scientific study of scientific method. This area is directed toward two objectives: first, an increase in the efficiency of research within familiar areas and, second, an opening of new areas to which familiar and newly developed scientific methods can be applied.

How does a methodologist contribute to increasing the efficiency of a process of estimating the cost of a proposed job? He begins with a recognition of the obvious fact that the process is one of estimation. Then he asks, "What are the fundamental aspects of the estimation process?" Every estimation procedure involves four questions:

1. What kind of data is pertinent to the problem?
2. How should the data be obtained?
3. How much data should be obtained?
4. How should the data be analyzed?

On what basis can these questions be answered? To say we want the "best" answer helps little unless we have an explicit criterion of "best." One such criterion which has had wide application is that of minimizing expected costs. That is, we can answer these four questions in such a way as to minimize the sum of the cost of obtaining the estimate and the cost of acting on the basis of the estimate once it is obtained. A correlated criterion which can also be used is that of maximizing the gain.

To see how the criterion of minimum cost can be used, let us first consider a very simple situation. Suppose we have a population of five elements whose values along some scale are 2, 3, 6, 9, and 10, respectively. The average value for the population, then, is 6. Now, suppose we do not know this value but want to estimate it on the basis of data obtained from a sample drawn from the population. It would be possible to select samples of 1, 2, 3, or 4 elements. How may should be selected? Let us see what is involved in getting a rational answer to this question. First, you will observe in column A of Table I all the possible samples, for each size, which can be selected

TABLE I

Sample.	A	B	C	D	E	
Size	Sample	Estimate	Error	Cost of Error	Expected cost of Error	
1	2	2	−4	$24.00	$ 4.80	
	3	3	−3	18.00	3.60	
	6	6	0			
	9	9	3	9.00	1.80	
	10	10	4	12.00	2.40	
					12.60	
					3.00	
					15.60	=TEC
2	2, 3	2.5	−3.5	$21.00	$ 2.10	
	2, 6	4.0	−2.0	12.00	1.20	
	2, 9	5.5	−0.5	3.00	0.30	
	2, 10	6.0	0			
	3, 6	4.5	−1.5	9.00	0.90	
	3, 9	6.0	0			
	3, 10	6.5	0.5	1.50	0.15	
	6, 9	7.5	1.5	4.50	0.45	
	6, 10	8.0	2.0	6.00	0.60	
	9, 10	9.5	3.5	10.50	1.05	
					6.75	
					6.00	
					12.75	=TEC
3	2, 3, 6	3.67	−2.33	$14.00	$ 1.40	
	2, 3, 9	4.67	−1.33	8.00	0.80	
	2, 3, 10	5.00	−1.00	6.00	0.60	
	2, 6, 9	5.67	−0.33	2.00	0.20	
	2, 6, 10	6.00	0			
	2, 9, 10	7.00	1.00	3.00	0.30	
	3, 6, 9	6.00	0			
	3, 6, 10	6.33	0.33	1.00	0.10	
	3, 9, 10	7.33	1.33	4.00	0.40	
	6, 9, 10	8.33	2.33	7.00	0.70	
					4.50	
					9.00	
					13.50	=TEC
4	2, 3, 6, 9	5.00	−1.00	$ 6.00	$ 1.20	
	2, 3, 6, 10	5.25	−0.75	4.50	0.90	
	2, 3, 9, 10	6.00	0			
	2, 6, 9, 10	6.75	0.75	2.25	0.45	
	3, 6, 9, 10	7.00	1.00	3.00	0.60	
					3.15	
					12.00	
					15.15	=TEC

from the population. For the moment, let us assume we are using a simple random sampling procedure; that is, one in which each possible sample has the same chance of being selected as any other sample of the same size. Further, suppose that we use the average of the sample as an estimate of the average of the population. In column B you will observe the resulting estimates. Now, the inaccuracy or error of each estimate can be determined simply by subtracting the true population average (6) from each estimated value. The results are shown in column C.

Now, let us suppose that each error of overestimation costs $3.00 per unit of error, and each error of underestimation costs $6.00 per unit of error. Then, in column D, we can enter the cost associated with each error. But we do not know beforehand which error will be made. Nevertheless, we do know what the chances are that we will make that error. For example, there are five possible samples of one element, and—according to the method we are using—each sample has an equal chance (1/5) of being selected. Therefore, each error has the same chance (1/5) of being incurred. Then, the first error listed for samples of 1, is—4, and its cost, $24.00 will be incurred in the long run 1/5 of the time. On the average, then, this error will cost 1/5 ($24.00), or $4.80 per estimate. This is the expected cost of this particular error. The expected cost of each possible error can be computed similarly. They are shown in column E. The total for each group in column E is the total expected cost of error; that is, the average cost of error that will be incurred if the procedure is used repeatedly.

Now, suppose each observation costs $3.00. Then, the cost of observation for the various sample sizes is $3.00, $6.00, $9.00, and $12.00 respectively. If we add this sum to the total expected cost of error we obtain the total expected cost of the procedure, TEC. You will observe that, for this illustration, samples of two elements are the most economical in the long run.

Similar computations could be made for other sampling and estimating procedures which can be applied to this problem. That method should be selected which would yield the lowest total expected cost.

The procedure just illustrated can be expressed in general terms, as follows: Let e_i represent an error of estimation. Further, let $C(e_i)$ represent the cost of that error, and $P(e_i)$ represent the probability of making that error. Then, the expected cost of that error is $C(e_i)P(e_i)$, the product of the cost and the probability. The total expected cost of error can then be expressed, as follows:

$$C(e_1)P(e_1) + (C(e_2)P(e_2) + \ldots + C(e_n)P(e_n) = \sum_{i=1}^{n} C(e_i)P(e_i)$$

Now, if K is the cost of taking one observation, and n is the number of observations taken, then nK is the cost of obtaining the sample. The total expected cost of the procedure (TEC), then is given by the following equation:

$$TEC = nK + \sum_{i=1}^{n} C(e_i)P(e_i)$$

One difficulty seems to appear: in a real situation—though we might be able to determine the cost of a specific error—how can we determine the probability of making that error? But this is not a real difficulty because sampling and statistical theory provides estimates of this probability for any sample size. That is, the probability $P(e_i)$, can be expressed as a func-

tion of the sample size, n, and the error e_i:

$$P(e_i) = f(n,e_i).$$

To determine which value of n minimizes the total expected cost of the procedure the methods of differential calculus can be used. We take the derivative of TEC with respect to n, set the result equal to O at the minimum point, and solve for n.

Now, you might say, suppose this approach is applicable to estimating characteristics of a population, how can it be used in estimating the cost of a job? Well, let us see.

First let us set aside practicality and set up an ideal procedure, one we would like to follow if we could. Then, we can consider how close to the ideal it is possible to come.

The variables involved in job-cost estimating can be represented, as follows:

t=hours spent in preparing the estimate;
c=cost per hour expended in preparing the estimate;
p=probability of getting the contract for the job estimated;
k=estimated cost of the job to the estimators;
k′=actual cost of the job (if obtained) to the estimator;
k″=contract price of the job;
G=expected gross profit from the job;

The expected gross profit can be expressed in the following equation:

$$G=p(k''-k')-(tc).$$

The values of p and $(k''-k')$ can ideally be expressed as functions of t, the time spent in preparing the estimate; that is

$$p=f(t)$$
$$(k''-k')=g(t)$$

To maximize the expected gross profit, an optimum value of t is sought, just as in the earlier illustration an optimum sample size was sought. This optimum time can be defined mathematically, as follows:

(1) Take the derivative of G with respect to t:

$$\frac{dG}{dt} = \frac{d[p(k''-k')-(tc)]}{dt}$$

$$= \frac{d[f(t)g(t)]-(tc)}{dt}$$

(2) Determine if $\frac{dG}{dt}$ is a maximum.

(3) If it is, set $\frac{dG}{dt}$ equal to zero, and solve for t. The value of t thus obtained would maximize the expected gross profit.

So much for idealizing the procedure. To use the procedure, estimates of the function f and g are necessary. These values might be obtained by preparing and analyzing data compiled in the following way (see Table II):

TABLE II

(1) t	(2) k	(3) k″	(4) Contract obtained (yes-no)	(5) if-yes k′	(6) k″-k′

By using such a table on the estimating procedure employed by a company, estimates of the functions might be obtained. But even if such estimates cannot be obtained, the model can serve as a heuristic device for making explicit what data should be obtained in the future so that the estimation process can eventually be brought under control; that is, it opens up the possibility of eventual (if not current) improvement in cost estimation.

This particular model for job cost estimating is not applicable to all

cases; variations would be required by special cases. It is applicable to the company we are considering.

The construction of an ideal procedure does not provide a final answer; rather it provides a beginning for obtaining a provisional answer. For example, in job-cost estimating, the job-cost itself is usually a secondary estimate. By this I mean that some other property of the job is usually first estimated, such as manhours required, or material required. Then a conversion factor is used to translate this estimate to one of cost. Hence, it is critical to know how good is the primary estimate, and in particular, how reliable is the conversion factor. This phase of estimation was the primary concern of the engineering member of our team.

Further, assuming that a good method has been developed, there is no guarantee that it will be used efficiently unless certain organizational requirements are met. These requirements are psychological and social in character. Cooperation and communication among participants in the organization's activity are necessary for the successful application of any problem-solving procedure. These aspects of the problem were studied by the psychologist and the communications expert of our team.

III—THE ROLE OF COMMUNICATIONS

The analogy drawn between a business enterprise and an organism is more than a figure of speech. In maintaining its functions and integrity, a business enterprise solves problems which are essentially of the same kind as those which organisms face. Just as an organism, constantly faced with the ever-changing environmental situation, must constantly adjust its behavior so as to meet the situation adequately (that is, preserving its integrity and its functioning capacity), so must a business enterprise.

We use the term "organization" to designate the faculty which living organisms have in dealing adequately with situations. The essential part of the organization is the communication apparatus. When the presence of obnoxious substances or of food is reported by the sense of smell, and the muscles take appropriate and coordinated action, we know that the organism's communication apparatus has functioned properly.

Similarly in business, when certain conditions of the market are evaluated by certain responsible personnel, and appropriate action is taken by other responsible personnel, we know that effective communication has occurred.

Before we examine the role of the communication process in an enterprise as it affects cost-estimating procedure, I would like to say a few words about the communication process in general. Whenever it occurs, communication can be of many different kinds, and depending on what role of communication we are talking about, we can classify its occurrence accordingly.

For example, we can classify different kinds of communication flow according to the functions they perform in the organization. Suppose we have an organization chart such as is represented in Table III.

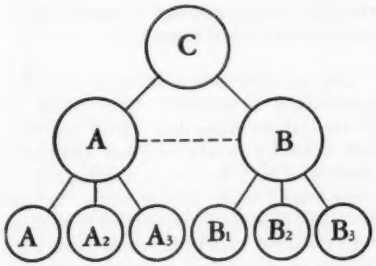


TABLE III

Here authority is concentrated toward the top. Ordinarily, communications flowing up the channels carry information which results in decisions affecting the sources of the information.

Communications flowing down the channels ordinarily carry directives. Communications flowing along the same level of authority (as from A to B) serve to coordinate decisions affecting separate groups. In some types of organization, for example, in the rigid military structure where everything goes "through channels," information can travel only up and down the channels but not across.

Besides this spatial or "topological" classification of information flow we may classify communication according to the role it plays in the time dimension. One can communicate with the past, with the present, and with the future. One communicates with the past by consulting available records of what has occurred. Memory, of course, is a special kind of record. One communicates with the present by utilizing the available spatial channels of communication within the organization and those to and from the outside. For example, one obtains information from publications, and one disseminates information through advertising. One communicates with the future by making records to be available at a later time.

There are many other aspects to communication. In fact, the subject forms today an entire field of inquiry with its own areas of research and specialization. But for the purposes of our discussion, an examination of these two aspects—the spatial and the temporal—will suffice.

The cost estimating procedure obviously involves an evaluation and a decision. As such, the procedure is an act of adjustment to a certain stimulus; that is, a prospective job which an enterprise would like to undertake. The sort of decision made will determine whether the job will be undertaken at all, whether—if undertaken—it will be profitable, and whether its completion willl enhance or inhibit the opportunities for undertaking other jobs in the future.

From the point of view of a business enterprise in a competitive situation the criteria for a sound cost estimating procedure are perfectly clear: The cost must be estimated neither too high nor too low. For, if it is estimated too high in a competitive market, the chances of undertaking the job at all will be diminished, and if it is estimated too low, the job will not be a profitable one, or, if adjustments in the contract are allowed, the good-will of the customer may be lost.

Now then, how is one to know whether one makes 'good' estimates. An obvious way to find out seems to be through the examination of past performances. But what can be learned from such examination? As an example, allow me to take the case of one industrial enterprise where our team recently conducted a diagnostic analysis of the engineering cost estimating procedure.

An examination of the company's records showed that "over-run" rath-

er than "under-runs" were the rule on the jobs undertaken. Several of the company's executives were interviewed on this matter, and all agreed that jobs tended to over-run, a fact which they interpreted to mean that under-estimates rather than over-estimates of cost were the rule in their company. But does it necessarily mean that? To see whether over-estimates or under-estimates prevail, one must examine *all* the jobs for which the company has prepared and submitted bids, not just those which were actually undertaken, since it stands to reason that many of the over-estimated jobs were lost to competitors, and therefore, that the ballance was stacked in favor of the under-estimated jobs.

None of the executives interviewed brought out this point. Instead, they blamed the predominance of under-estimating on a lack of proper information, on unreliable formulae for estimating labor costs, on the decline of productivity of the American worker, which, in turn, they explained as stemming from his rising sense of security, labor union activity, etc., etc.

Now, it may well be that all of these factors are operative. However, it is obvious that the situation can be hardly effectively improved if one does not know which factors are the most important, or at least, which factors can be most directly affected. It is possible that the American workers' "sense of security" is somewhat responsible for a declining rate of profit—although I wouldn't bet on that—but if some other factors can be tackled more easily, it stands to reason that it pays to concentrate on them rather than give way to nostalgia for the 'good old days' of speed-up incentives.

I repeat, in order to change any situation one must uncover the factors which one can *effectively manipulate*. This is true to the extent of being trite; but many such obvious truths, although recognized on a verbal level, are seldom *acted* upon.

Let us now come back to the cost estimating procedure. One must, of course, determine first of all whether one actually produces good estimates. And, as I said before, a mere count of over-runs and under-runs is not enough. It must be expected that there will be some bias in favor of over-runs in any company's record because under-estimated jobs which tend to over-run are selected for in a competitive situation. The question is not whether there is a bias. The question is how much bias should there normally be? This question can be answered only by appropriate research. The techniques of such research are beyond the scope of this paper. They obviously fall within the realm of communication, in this case the availability to the company of information concerning the status of over-runs and under-runs in other companies, and certain statistical considerations such as the relation between the size of the over-estimate and the probability of losing the prospective contract, and similar matters.

Let us now suppose that this information has been obtained, and that a discrepancy is found between the actual and the optimum estimating habits. The question now arises on how to improve those habits. This brings us to the functioning of the communication apparatus within the company. It is another truism to say that the better this apparatus functions the more accurate will be an evaluation of the important factors which determine the estimate. It is, however, necessary to be more specific with regard to what constitutes a good communicative apparatus. One could ask the following questions:

1. *Are the prescribed channels of communication adequate to carry all the*

information necessary for the cost estimating procedure?

In any business organization there are prescribed channels of communication. They may not be as rigid as in the military, but they nevertheless exist. For instance, the dissemination of work sheets, blue prints, etc., is obviously determined by the quantity of the duplicated material, and this constitutes a constraint on the available channels of communication.

2. *Is too much information sent through the prescribed channels?*

One of the important complaints made by the technical personnel of the company which is serving as a case history was that they had to spend too much time abstracting the information they actually needed from that which was sent to them.

3. *Are the prescribed channels actually used?*

In other words, are the directives and instructions actually read, or are they merely disseminated? A pertinent question is also whether they are written in a language which is conducive to being read.

Or, on the personal communication level, if it is expected that personnel will seek advice from their more experienced superiors, do they actually seek that advice? Is the personality of the superior such that his subordinates want to seek his advice?

4. *Are the informal channels of communication utilized?*

Anyone who has been in the Army knows that if communication had been strictly confined to "official channels," we might have lost the war. Every supply officer knew that the way to get supplies on time was to be buddies with all the other supply officers in the theater so that one had informal "under the counter" information about what was available where.

In a business organization such informal channels have an opportunity to operate where people are friends as well as co-employees. In this way information, experience, and know-how are exchanged that never have a chance of getting into the directives, circulars, etc., because the people who write the directives do not speak that sort of language.

5. *Is there "feed-back"?*

When directives are sent down the line certain actions result. Do those who send the directives know the effects of those actions, and, if so, do they evaluate those effects so as to send 'better' directives the next time? This does not ordinarily happen if decisions are made exclusively in the air-conditioned solemnity of the directors' meeting, and the direct action is confined to the racket of the shops and the tribulation of the salesman.

So much for the general operation of the spatial communication apparatus within the company which influences the decisions which, in turn, determine the cost estimating procedure. When we turn to the temporal aspects of communication, the evaluation of records, the bearing of this process on cost estimating procedure becomes ever more apparent.

Here, the operation of feed-back is of prime importance. Since cost estimating procedure is constantly improved if a learning process occurs; that it, if the results of each operation are fed-back into the information on which future operations will be based.

One must, of course, have accurate records. Here, the structural make-up of the organization is again important. One cannot have accurate records if—as is the case in some companies—the various departments compete with

each other trying to maneuver the estimates in such a way as to minimize the costs charged to them in order to show a departmental gain regardless of the fact that there is a company loss. One cannot have accurate records if the "incentives" used in the company consist of threatening people with disfavor if they make mistakes; this usually results in doctored-up records.

But even with the most faultless records no progress can be expected in the cost estimating procedure if the procedure itself is not modified as a result of experience. Here again, the analogy between the enterprise and an organism becomes meaningful. The ability of the organism to adjust to challenging situations only seldom consists of a complete repertoire of reactions to standard sets of conditions. In all higher animals this involves the capacity to learn; that is, to change the behavior patterns with each new situation so that the next time the situation occurs it will be met more effectively.

Thus, an enterprise which continues to use the same estimating procedures year after year because that is what each department head is used to and that is what he teaches his successor, is not functioning as an organism in a rapidly changing environment should function. A most important aspect to the temporal communicative process is, therefore—aside from the availability of accurate records and the ability to evaluate them—a learning potential, a feed-back device in which the accumulated experience actually counts.

This happy state of affairs can come about only if the responsible personnel are aware of how the communicative process operates. And this awareness can come only with a broad background and interest in things other than those immediately concerned with one's job.

IV—AN ENGINEER'S APPROACH

To an engineer the solution of any problem resolves itself into determining the objective or objectives of the solution, the degree of accuracy desired and the kind of data that are necessary to achieve the stated objectives.

The objective of an estimate is to provide a concern with the cost of doing a unit of work. The term unit of work is used loosely as it might mean the cost of producing a can label or the cost of producing an entire manufacturing plant. The estimate itself might be used in various ways. It may be used to establish a firm bid quote on a unit of work or in a control function like scheduling, purchasing, and preparing a budget.

The degree of accuracy required may well vary with the use that is to be made of the estimate. It is a well known fact that the cost of producing an assembly rises with the degree of precision required in the manufacture of its components and it is logical that the same would hold true for the expense involved in preparing all but the simplest of cost estimates.

We assume that a company is in business to make a profit, and to provide the investors with a reasonable return on their investments in the form of dividends. We shall assume that the management's process of decision-making is designed to achieve this goal continuously. Furthermore, no designed process or procedure is ideal, or perfect, or functions so well that it needs no improvement. As Dr. Rapoport has pointed out, it is necessary for a business to have the quality of being

able to adjust to changes which occur continually, and quite similarly to the same ability of the biological organism to adjust to ever-changing conditions. While this is generally true, it applies even more so to the design and execution of procedures of the importance of cost estimating.

The characteristic of continuous improvement is achieved by considering a procedure "imperfect," and by providing a feed-back mechanism by which the procedure itself can be objectively evaluated and improved. This application of the feed-back principle will not merely detect and correct defects which were incorporated in the original design of the procedure, but also defects arising out of changing conditions not anticipated at the time of design.

The examination of what data are necessary for producing a cost estimate may begin at the point of cost accounting; that is, with the record of the work after it has been done. The cost accountant assembles the cost of a job by dividing the expenditures into three categories:

1. Direct Labor Cost; that is the cost of all labor which can be directly allocated to a specific job (exclusive of overtime premium, etc.).

2. Materials Cost; that is, the cost of all materials which go directly into the making of the product.

3. Overhead, or Burden, that is, the accumulation of all other expenditures of general nature which cannot be (a) directly associated with one job, and (b) such expenditures which can be directly allocated to one job but which would distort the record of the job cost, such as overtime premium, or substandard performance "make-up." The total overhead is prorationed by some fixed formula over all the jobs done within an accounting period.

The accumulation of such costs is usually done in a systematic fashion. Labor tickets are provided for direct and indirect work, and time and type of work are recorded. Materials are similarly controlled through inventory and purchasing procedures. The determination of overhead and its distribution is of lesser concern to the engineer, particularly in view of the fact that he can seldom exercise any sort of control over such expenditures.

The accuracy of the accounting of costs becomes a function of the completeness and veracity of the original recording of labor and materials, and their correct allocation to the proper job. Thus, it may be said that cost accounting ideally is a replica of what has actually happened.

This is not so in cost estimating. Estimating, in effect, is a prediction of what a job, a service, or a product is going to cost. The accuracy of such a prediction depends upon the estimator's knowledge of (1) the final design of the product to be manufactured; (2) the materials required; (3) the operations necessary to be performed; (4) the tools and equipment by which these operations will be performed, and (5) the time required to perform each operation.

The development of reliable records to provide the estimator with such information depends to a large degree upon the type of industry which produces the product. An industry which manufactures large quantities of the same product can, in time, establish quite accurate records. Such records usually take the form of operation instruction sheets, routing sheets, and standard time tables. The routing of a part, sub-assembly, etc., can be, and often is, a part of the engineering function; that is to say, that the engineer does not merely specify what is to be made, but also how it is to be made,

the tools to be used, the methods to be employed, etc. Time values can be established by numerous methods.

The availability of such records, and their reliability, however, decreases considerably as the size of the average production run decreases. To achieve a relatively high degree of reliabiilty in an industry having an average production run of, say, 10,000 pieces is not too difficult. The industry which never produces more than 500 pieces of one design has a more serious problem of developing accurate data, and its problem of producing an estimate is considerably more difficult. As the size of the average production run approaches 1, the difficulties of producing a reliable estimate grow unproportionately.

Such difficulties are even further amplified in companies engaged in so-called contract manufacturing, such as the art of metal industry, fabricators of sheet metal systems as heating, ventilating, and air-conditioning, and special purpose equipment builders, as for example the oil-well equipment and supply industry, and special materials handling producers. Within this class of fabricators a further difficulty may be observed in the cases of those manufacturers whose policy it is to render a complete service, that is to say the concern that merely fabricates, assembles, and erects according to engineering design and detail furnished by the buyer is confronted with an estimate problem of somewhat lesser magnitude than the company which also engages in the design of the equipment, its fabrication, subassembly, job site, assembly, and its estimator with a finalized and detailed erection. The former can at least supply design. The latter is forced to produce an estimate on the basis of a preliminary design; often produced with little or no knowledge of the job site conditions. While it is by no means intended to convey the impression that the intrinsic difficulties of estimating on all levels of manufacturing are widely different, it is pointed out that the type of production process varies from mass production to single unit production types, and that the difficulties of producing a reliable estimate increase with the decrease in the production run size.

The most difficult conditions are encountered by the company that renders the most complete service, that is to say, the one which includes in its estimate the cost of engineering, fabrication, job site assembly, and erection of an installation, and which uses such an estimate to make a firm bid or a binding quotation to the prospective buyer. It is such an organization that we are considering here. This places a high premium on the accuracy and completeness of the preliminary design, or proposal drawings, and it entails a certain risk of spending time on this phase of work, particularly in view of the experience of such industries that the yield of contracts received varies from 5% to 25% of contracts which were bid. This would indicate that even under the most favorable conditions, there is one chance out of four that the bidder will receive the contract, and normally the risk would be much higher. The problem of optimizing cost estimating time has already been discussed by Dr. Ackoff. I shall concern myself with a discussion of the types of information which are necessary to evolve an accurate engineering cost estimate as they are related to the particular type of industry described before.

The cost of materials is, obviously, a major item in any estimate. Materials, in this case, are divided between structural items and machinery and equipment items. The structural items consist primarily of rolled steel shapes, rivets, plates, etc., for the superstructure, and do not, in general include structural items such as reinforcing steel for concrete foundation work.

The foundation work is generally supplied by the buyer.

The cost of structural materials such as rolled steel shapes is primarily a function of their weight. The selection of structural materials which are in the main load-carrying elements depends upon the spans, the loads, and on the type of construction, that is, riveted, welded, simple or statically indeterminate. These decisions must be made before even an approximate analysis of the size of the structural members can be made. Since most structures are indeterminate to some degree, it is necessary that simple, approximate formulae be evolved, in certain cases, for the determination of the sizes of structural members. These formulae can be improved by subsequent correction possible through the more exact analysis of the actual jobs which are engineered.

The selection of equipment items depends on capacities, cycle times, and operating conditions. Their selection is simpler, generally speaking, than that of the structural items.

Perhaps the most difficult phase of the estimating job is the estimating of shop fabrication time. It was previously pointed out, the average production run of the company under consideration is 1, type, sequence of operations and methods of handling, etc., are decisions made in the shop, routing is non-existent, and hence, no operational break-down exists on the basis of which operational times could be accumulated. "Indirect" labor is often included in "direct" labor times, rendering historical information extremely unreliable. The establishment of a routing routine and the determination of standard times by some established system would be uneconomical because of the fact that only one piece of equipment is being produced. This introduces so many variables and unknowns into this problem that it presents a real challenge.

It is obvious that there is no one simple answer to this problem, such as "shop hours per ton of steel fabricated"; even though this practice is widely used in this and many similar industries. This becomes even more apparent if we take, for example, just a simple ¼ inch flat plate tension member which is joined to its supporting member by a single V-groove butt weld. If we double the load in our original design, then, the size of the member and consequently its weight would double. Let us assume that we double the size of the member by making it the same width but ½" instead of ¼" thick. The cost of preparing the ends of the two members for welding might be roughly the same because the preparation time is a function of the width of the pieces rather than the thickness of the material. If we examine the time necessary to perform the actual welding by taking the time values from Lincoln Electric's *Procedure Handbook of Arc Welding*, we find that the ¼" plate can be butt welded at a rate of 27 ft./hr., and the ½" plate can be welded at the rate of 19 ft./hr. There is no allowance in these allotted times for positioning and turning the work, shipping, etc., as these would obviously depend upon the actual conditions and facilities existing in the particular shop and on the particular job. Comparing the actual time of welding, however, we find that a member twice as heavy may be connected in 1.42 times as long. The amount of electrode used, however, for the ½" plate is about three times that for the ¼" plate.

The cost per pound of producing an installation can often, by coincidence, be a good criterion of the cost of producing similar installations. I was amazed at some figures compiled by a Cleveland manufacturer of household

appliances who took eight different competitive makes of a particular appliance, completely dismantled them and prepared detailed estimates of the cost of producing each manufacturer's appliance. The designs were widely different particularly in the number of fastening operations necessary in assembly. The lowest having about 100 such operations and the highest over 200. When the costs were completely analyzed it was found that the variation in cost per pound between the high and the low was about 2 cents. One can find the same coincidence by comparing the cost of similar models of the big three automobiles. No doubt the cost per pound would be approximately the same, however, it would certainly be an error to assume that this is the cost per pound of all automobiles.

The case in point is simply that a system of record-keeping must be adopted by which unit times for some adequate operational units will evolve. It is very doubtful that a simple parameter like weight of steel fabricated will suffice, except in the case of geometrically similar structures fabricated in a similar manner. It could be expected that weight, length of member, type of operation, and the geometric shape of the sub-assembly are pertinent variables to be considered in estimating shop times. These variables can be correlated by setting up a system of record-keeping on each job so that eventually reliable information becomes available to the estimator.

It is difficult to predict the time necessary to engineer a job because it is almost impossible to evaluate the efficiency with which a professional man does his work. Engineering, is, in part, a creative activity, and as such does not lend itself too readily to an accurate performance evaluation. One factor which must not be overlooked is that additional time spent in engineering may well show up as a savings in materials, shop labor, and erection time. Here again, the importance of record-keeping in the engineering department and in the shop cannot be over-emphasized as a way to evaluate the existence or lack of such savings.

Finally, the estimator is faced with another difficulty. In the case at hand, erection jobs are done by crews obtained from local "hiring halls" under the supervision of the seller's erection superintendent. This is unfortunate from the estimator's point of view because of the fluctuations in the quality of the crews, not merely from job to job, but even from period to period on the same job. In some instances it may mean that all of the skills required for the efficient completion of the erection job are not even available to the superintendent. Accurate daily reports on man hours and equipment hours prepared and maintained with uniformity, and analyzed in terms of significant parameters like weight, length, geometry, and job site conditions might yield information on the basis of which the estimator could make predictions with a higher degree of reliability. The need for accuracy of these figures cannot be overstressed. If for example, an erection superintendent records the time for setting a pier leg against the span erection time in a way this his figures will jibe with his erection schedule, then of course, nothing is learned.

A post-mortem on each job—whether it went well or badly—would be a further part of a feed-back mechanism by which the process of self-improvement and self-education could continue.

The economical development of a reliable engineering cost estimating procedure depends upon accurate record-keeping by the proposal engineering department, the engineering depart-

ment, the purchasing department, the shop, and the erection superintendents. A cooperative effort of all of these in correlating these records with the significant cost parameters will evolve information to the hands of the estimator which will continuously increase the degree of reliability of his estimates. This will provide the company with a higher yield of contracts obtained, with an assured margin of profit to be attained, and last but not least with a knowledge that any recurring inefficiencies throughout its enterprise can be dealt with in a systematic fashion.

V—HUMAN FACTORS

It may seem strange to you to include a paper dealing with problems of human relations in a symposium concerned with engineering cost estimating practice. I think that you are probably all aware of, and perhaps accept, the idea that there are human relations problems involved in selling and in managing. Nobody is so naive, nowadays, to think that a good product sells itself, although even if it did, there would still be human relations problems involved, in that a need or desire for a product must exist in, or be felt by, the potential customer before the product will be bought.

Most people, I think, now realize that a company does not run itself on the basis of a good organization chart alone, but that the needs, wishes, and motivations of the individual members of the company and the interaction and inter-relationships between the individuals and groups must be recognized and dealt with to insure smooth operation. Even the design of an organization chart, and surely—what is perhaps more obvious—its proper functioning, is more a problem in human relations than one of technical planning alone. Many managers, I am sure, have stubbed their toes on the consequences of the oversimplification that occurs in organizational charts which forget the individuals and see only their defined functions.

I believe that most people—at least those people who are charged with the responsibility for management—realize that a company is more than an aggregate of capital stock or equipment—physical plant or merchandise—more than an aggregate of methods, techniques, or operations—more even than an aggregate of individual brains, talents, and personalities—and more than a mere additive combination of any or all of these factors.

But I wonder how many people, even those engaged in management, view a company—any company—as a social organism, subject to the same social laws as any other social organism and understood only by the same methods of conceptualization which apply to any other social organism. Any social organism, at the human level, has its roots in the relations between and among the individual human beings comprising it, and problems associated with human relations permeate every level of operation of that social organism, even engineering cost estimating practices.

That accurate estimating is an operation that is vital to the success of a business enterprise needs hardly be argued or defended. Estimates which are too high discourage potential customers—and a business cannot exist without customers; estimates which are too low eat into profits, or result in losses—and a business cannot long survive on losses, or merely breaking even. The purpose of estimating, then, is to arrive at a reasonable price for

the merchandise; reasonable from the points of view of both the buyer and the seller; it must be within the means of the buyer to buy, and it must at the same time allow a fair margin of profit to the seller.

What is involved in the process of estimating? The discussions of my colleagues on this panel seem to permit a general statement that estimating is a matter of accumulating and organizing the objective and observable facts, converting these facts into dollars-and-cents measures, and totalling these measures to arrive at a reasonable price for the merchandise. You may ask, What is psychological about that? You may be willing to grant that there are psychological factors involved in the matter of a "reasonable price"—many papers have been written, and read by all of you, which concern themselves with "the profit motive" and "buyer needs and resistance." But where do problems of human relations enter into the estimating procedures themselves, which are technical and factual in nature, however complex the technical problems may be?

In my overly simplified definition of the estimating process I emphasized the words "facts" and "factual." We tend to make a sharp distinction between matters of fact and matters of opinion or inference or speculation. Somehow facts, even though they may be unpleasant or distasteful, have considerably more respectability than ideas or theories. We tend to look upon "facts" as entities having an independent existence in the external world of reality as contrasted with ideas or theories which dwell and have their being only in the minds of men. Facts give us a feeling of comfort and security, for they are tangible things we can grasp, hold on to, and lean on for support.

It is perhaps too philosophical to argue here the matter of whether or not a "fact" has any existence at all unless it is observed. You would perhaps be more willing to accept without extensive argument or defense the idea that a fact has very little, if any, significance unless it is observed, interpreted, and reacted to. That a tree falling in a forest makes a noise is a "fact" that we all accept, although philosophers have been arguing for years as to whether or not there is any noise if there is no ear to hear it. But whether or not the falling tree makes a noise makes very little difference to anyone (except maybe the philosophers) unless the noise affects someone in some way — in other words, unless it is heard, interpreted, and reacted to.

Now, for a fact to be observed, there must be an observer. For it to be interpreted, there must be a perception and a mind to perceive. For it to be reacted to, there must be communication. So, in this sense, a fact has no meaningful existence outside the mind of the observer; consequently, what we glibly call a "fact" is not the phenomenon itself but the subjective experience of the objective reality.

Armed with this conception of "fact" it would be possible to examine and analyze each step in the estimating process in terms of the observation, interpretations and communications involved in order to determine the degree to which psychological or human relations factors enter into each. Wherever estimating practices seem to yield unsatisfactory results, such as systematic analysis would undoubtedly be fruitful and probably necessary in order to arrive at optimum procedures. However, this would be a task far beyond the scope of this paper which can only point to areas where human relations factors play an important role. I

can only hope that given this orientation you can make your own analyses on whatever level may be most useful to you.

Since much of the estimating process is based on record of one kind or another, let us consider some of the human problems involved in the construction and utilization of such records. Records are frequently looked upon as facts which can be used as a basis for estimating with a high degree of confidence. But, just what is a record? It should be remembered that a record is merely a representation, more or less complete, of an observed phenomenon. Complete records (examples of which might be motion pictures and sound recordings) must be condensed in order to be effectively utilized. For a phenomenon to be observed there must be an observer. What are some of the factors which may influence an observer in making a record?

First of all, we might consider the effect on the record-keeper of his understanding of what use is going to be made of the record. I think that you would all agree that an observer who thinks his record is going to be used to keep tabs on the efficiency with which he handles his job to the end that decisions can be made as to whether he will be retained or fired, demoted or promoted, will be differently motivated from the recorder who knows that his record will be used merely in a compilation of anonymous statistics. The individual in the first instance is highly motivated to make the record the best possible showing, regardless of the particular kind of record he will be called upon to keep, whereas the individual in the second instance has less at stake, or conceivably, it may be to his advantage to make a poor showing.

For an example of how the accuracy of records may be affected by lack of understanding of the use to which a record is to be put, we might look at the company already cited as illustrative of other points. In this company, the supervisor in the field keeps records of man hours spent on the various phases of the erection job. He, of course, is in possession of the estimates as to the "allowed" time which it was estimated would be spent on these various phases. He, quite naturally, in the face of any evidence to the contrary, looks upon these estimates as quotas to be met. The consequence of this view of his records as a measure of how well he has managed to direct operations so as to conform to the quotas set is fairly inevitably a juggling of figures so that the record of the actual time spent will agree as closely as possible with the estimates. If for some reason or other time is saved on one phase, or operation, the overrun on some other operation will be balanced by charging some amount of the overrun operation to the one which was underrun. In this fashion, errors of estimation based on such records keep on compounding themselves, encourage further juggling on future jobs, and do not provide for the refinement of the data from which the estimator produces the estimate. If the supervisor in the field were explicitly informed, and if he thoroughly understood that discrepancies between his records and the estimates would not be viewed as evidence of inefficiency, or even of efficiency, but that the sole purpose of the records was that they should serve as a basis for more realistic estimating, then he might be motivated to keep records which more accurately reflect what actually occurred on the job. It would be to his advantage to keep accurate rather than fictionized records, since time quotas could be set which it would be more nearly possible to meet.

Whether or not an observer will deliberately falsify a record depends on

additional psychological factors which must be understood in order to minimize the possibility or probability of falsifications occurring, and in order to evaluate the usefulness of any given record. The degree to which a person will resist the temptation to falsify or distort a record depends not only on the character of the individual—that is, his fundamental honesty—but also on his estimation of the importance of the record to him, personally, and to others or the company as a whole. If he thinks, for example, that his record will simply go to swell the already voluminous accumulation of papers that nobody ever looks at, he is not likely to view accuracy as very important. Demonstrating to him how his record is a vital link in the chain of company operations, and that as such it is important to the welfare of the company, and thus ultimately to his own welfare, is a problem in human relations. If the importance of the record cannot be demonstrated it is probable that it should not be kept at all.

I should like to insert a footnote here with regard to the conception of fundamental honesty as a character trait by pointing out that all we mean by this is the degree to which an individual can withstand the pressure exerted by his estimation of the advantage to himself of being honest or dishonest, and his estimation of how much distortion constitutes dishonesty. This is never a constant factor but one that varies with the situation and the individuals' own needs at a particular time.

Deliberate or semi-deliberate falsification is not the only source of error in recording. Observations to be recorded involve the perceptions of the individual making the observations. There is already an impressive body of evidence, accumulated from systematic and rigorous investigations, that the way in which an individual perceives an event is a function of his own highly subjective needs and tension systems. Perception itself can be, and often is, interfered with, narrowed, distorted or even entirely blocked off by highly individualized factors which are psychological in nature. Interpretation of the events perceived can, and often does, result in further distortion, depending on the subjective meaning which the perceived event has to the individual perceiving it.

So far we have discussed some of the problems involved in the accumulation of some of the data upon which estimates are based; that is, problems having to do with observations, interpretation, and recording. This is by no means the whole story, even so far as the gathering of information to be fed to the estimators is concerned. But let us go on to the next step in the estimating procedures: namely, problems associated with the utilization of the information accumulated. These are largely problems of communication and cooperation in which psychological factors are of paramount importance.

Cooperative effort not only makes possible the achievement of common goals but is in itself a product of common goals. In order to arrive at effective estimating practices for a complex operation the goals of estimating must be explicitly understood and accepted by all those who have a part in the process and procedures. It might seem that the goals of estimating are perfectly clear to anyone, but this is merely an implicit assumption, and implicit assumptions are not enough to insure cooperative team work. Explicitly stated and accepted goals do not make cooperative team work operative but they make it, at least, possible. A team of horses cannot pull together if they are each going in different directions.

Whether or not common goals can be formulated and agreed upon de-

pends upon the subordination of individualistic or personal goals, or it requires that personal goals be fitted into the framework of the common or company goals. For an example of how the pursuit of individualistic goals can interfere with cooperative effort, let us refer again to the company already cited.

In this particular organization a paternalistic form of administration prevails. Responsibilities are delegated without being clearly defined, and authority to carry out responsibilities is rarely explicitly bestowed, so that second-level management is maintained in a dependent relationship to top management. Rivalry between department heads is encouraged on the mistaken assumption that competitiveness will stimulate productivity and increase efficiency. The result of the struggle for the position of top favor (the personal goal of department heads) is to place a premium on techniques of defense and ingratiation rather than on techniques of effective cooperative behavior within the organization. It also results in feelings of tension, pressure, and pervasive insecurity on the part of those charged with the responsibility for operating profitably. These feelings manifest themselves in the psychological mechanisms of defensiveness and projection.

Defensiveness is displayed not only in an unwillingness on the part of various department heads to accept responsibility for errors, inefficiencies, and inadequacies in their own performances and in those of their departmental subordinates, but also in an unwillingness to view objectively, with the end of improving the situation, the errors which occur, and the inefficiencies which exist in their own departmental functioning as a whole.

Projection takes the form of placing blame on other department heads for "all" the difficulties that plague a given division. This tends to obscure the real nature of the issues, and prevents analysis of the situation in such a way as to recognize difficulties as symptoms of major problems which must be objectively formulated in order to be solved.

Although this kind of defensive and projective behavior is manifest in all areas of operation, its consequences are particularly felt in the estimating practices in this company, since the department heads have as one of their functions the responsibility for estimates having to do with their areas of operation. Consequently, the estimating process becomes a competitive rather than a cooperative enterprise. This kind of competitiveness, which implies attempts to enhance the value and importance of an individual or of a department to the disadvantage of others, results not in increased productivity but in the break-down of cooperative effort toward a common goal. Interindividual and interdepartmental jealousies and conflicts necessarily interfere with the objective appraisal and analysis of problems. Effective planning for efficient and profitable operation, of which estimating practices are a vital part, depends upon the objective analysis of difficulties and the impersonal consideration of alternative solutions to them. Defensiveness leads to a shifting alignment of individuals who temporarily join forces to attack another or others in order to divert attention from their own real or imagined shortcomings.

Difficulties are perceived not as objects of systematic appraisal and analysis but rather as material for justifying attack against the scapegoat of the moment, or as evidence justifying ineffectual performance, depending upon whether the difficulties encountered are within one's own province or in another's area of operation. Difficulties when perceived in this manner cannot

be seen as legitimate problems which must be squarely faced and dispassionately analyzed in order to be solved or dealt with by the best possible compromise.

It is commonly recognized that insecurity and pressure result in anxiety. The anxiety of a department head to enhance his prestige and the status of his own department, and pressure from other sources, may reflect themselves in estimating practices which take the form of either of two extremes. Estimates may be too low, to the end that not too large a proportion of the total cost will be charged to his department. In that case there is the danger that the company will lose money on the job. Estimates may be too high, to the end that performance will easily come within the limits set. In that case there is danger that the company will lose money on the job. Pressure from the sales department often results in the former error. Pressures from the fabricating and erection departments often result in the latter.

After engineering designs have been settled upon and the necessary information has been collected and evaluated the final step in the estimating process is a decision-making function. It is not possible to go into detail concerning the multiplicity of factors entering into this function, but I should like to draw your attention to at least one major source of error, or inaccuracy: namely, the problem of allowing for contingencies, or the safety factor problem.

The matter of the safety factor may be a fourfold problem in that allowances may be made both unconsciously and consciously but without explicit statement at both the departmental and the final, integrated cost levels. If "something" is added for safety at all four levels, the final estimates will be too high—if "something" is subtracted they will be to low. The problem of the consciously added or subtracted, but not stated, safety factor needs only to be recognized to be dealt with. An explicit statement as to how much has been allowed will obviate possible compounding of error.

The unconscious safety factor is a more difficult matter, and requires an understanding of personality factors in the individuals making the estimates in order to be recoginzed and dealt with.

You have considered with us some of the possible sources of error and inaccuracy in the process of estimating, some of the complexities and problems involved, and some of the scientific techniques which can be applied to the process in order to facilitate and improve the accuracy of procedures. It is as dangerous as it is easy to look upon practices and techniques as though they had an existence of their own, in isolation, and out of context.

I have attempted to draw your attention to the notion that techniques and practices do not carry out or apply themselves—they must be carried out or applied by some person or persons. Although this seems like a very simple and self-evident idea, it is astonishing what a complicating factor it is, and how often it is unrecognized or ignored. I hope I have been successful in pointing out some of the ways in which ignoring the human factor can prejudice the results of even the most carefully planned operations, and the most scientifically devised techniques.

NEW ZEALAND'S BIGGEST ELECTRICAL REPAIR JOB

COMMANDER ARTHUR C. BUSHEY, USN, RET.

THE AUTHOR

Commander Bushey is a registered architect and registered professional engineer in the State of Maryland. Since his retirement in May 1953, he has been engaged as a consulting engineer in Baltimore. During this period he has also been vitally concerned with research and development of laminated plastics, a project he fostered while stationed in Contract Design (Hull), Bureau of Ships from 1946 to 1952.

During his last year of active duty, he served as the Senior Assistant Supervisor of Shipbuilding and Naval Inspector of Ordnance and Assistant Industrial Manager, Baltimore. During World War II he was attached to the South Pacific Command, later serving as officer in charge of shipbuilding and ship repairs in New Zealand and commanding officer of the U.S. forces in Auckland.

The late King of England invested him as an Honorary Officer of the Military Division of the Most Excellent Order of the British Empire. He was also made an Honorary Commander in H.M. New Zealand Coast Guard and for his service in the South Pacific he was decorated with the Bronze Star Medal.

Twenty-eight of the first forty Navy Provisions Ships (AF) were engaged at some time during their notable World War II Service in providing food to the Army, Navy and Air Corps fighting men in the South Pacific. The war was almost over before we say any of the new ships. Many of the first AFs were conversions from private vessels which carried bananas and a few passengers. The jest made by one of the masters of the banana ships, "Every banana a guest, every passenger a pest," indicated in some measure the thoughtful care given by their owners to the physical care of these ships. But carrying bananas at 40°F. is far different from carrying meat at 15°F. from Auckland and Napier to not just one tropical base, but to a number of bases, opening the hatches and removing refrigerated cargo to provide food for military units, the quantity delivered depending on their needs and in a few instances limited by the capacity of the refrigerators ashore. The exigencies of war necessitated hasty conversions in the United States, a change from the earlier envisaged complete conversions. As a result, there was always an availability in Auckland for an AF or an alteration

or repair being made during loading at Princes Wharf, Auckland or the more difficult ones in the open roadstead of Napier. Most of the work revolved around the overloaded refrigeration plants. During the period 1943-1946 many of the AFs had their conversions completed in New Zealand.

A few of the AFs had difficulties in addition to refrigeration problems. The USS *Roamer* (AF-19) LCDR Oates, commanding, had a continuing propulsion engine problem until an availibility was squeezed in after she had worn out the original cylinder liners and almost two complete sets of spare liners made in New Zealand. The trouble was eliminated when her Burmeister and Wain 1850 h.p. diesel was practically rebuilt, and the thrust bearing relocated, a fault apparently built into the ship in 1935. An interesting side light of earlier days was our translation of her Danish instruction books into English.

Depth charges had corrugated the bottom of the USS *Delphinus* (AF-24), LCDR Armbrust commanding, and had caused a bad misalignment of her engine and tail shaft. Distribution of misalignment among the shaft alley bearings enabled her to continue until we found time to cut the 2500 h.p. Workman and Clark triple expansion steam engine adrift from her foundations, quite a feat because of the additional problems introduced by strict New Zealand laws relative to working in and near compartments not entirely gas-free; and jack the engine to a position of alignment with the tail shaft.

The most colorful AF task was that on the USS *Taurus* (AF-25). She was acquired by the U. S. Navy on 2 October 1942 and commissioned 29 October 1942. She was then 21 years old, having been built in 1921 in the yard of Workman Clark and Company, Belfast, Ireland. She was a single-screw ship, 325′-3″ long overall, with a 40′-4″ beam. Her propulsion plant consisted of three Scotch boilers and a Thompson-Houston turbo-generator amidships and a 3500 h.p., 3000 volt, propulsion motor in the stern. At full load her displacement was 6,600 tons, her draft 23′-0″ and her speed 13 knots. Her capacity was 96,600 cubic feet of refrigerated cargo.

As the result of damage incurred in a forward area, it was observed that the windings of the *Taurus* propulsion motor suffered progressive deterioration. In the latter part of 1944 performance of the motors and records kept by the ship and by us indicated accelerated decline. The *Taurus* was desperately needed and there was no available replacement. The obvious answer was to grant an availability in New Zealand.

The *Taurus* could be spared from the New Zealand-South Pacific Bases refrigerator run for a period not to exceed six weeks. After inquiry and deliberation, we decided to assign the job to Wm. J. Parlour, Ltd., Albert Street, Auckland. A project of this magnitude was new to New Zealand. My choice rested on the quiet confidence and stability of Mr. W. J. (Jack) Parlour, his conviction that the work had to be accomplished for the war effort and that it could and should be done in New Zealand, the closest and most logical base with respect to the South Pacific theater. The magnitude of the task was viewed with some apprehension by the New Zealand Government, so upon arrival of the *Taurus*, I was not astonished when Mr. W. J. Maskell, our Naval Engineer Overseer, Auckland and Mr. W. J. Parlour, both New Zealanders, and I encountered an Engineer Admiral from Australia, whose name Mr. Parlour and I have forgotten,

Admiral Boedell, R.N., from Wellington and Captain Bingley, R.N., in command of H.M.N.Z. Dockyard, Devenport, who met with us and LCDR Drake, commanding officer, USS *Taurus,* in his cabin. The New Zealand Government wanted the ship towed to Australia for repair, so the questioning of Mr. Parlour as to experience and capability became, in his words, quite lengthy and most vexing. Mr. Parlour had previously agreed with me to do the work and I was determined that it should be done in New Zealand to save precious time. My enthusiastic supporter then and always was Admiral Boedell. He proceeded to work on the other two members who were representing his Government with the ever present merry twinkle in his eye.

At the outset, I wish to make it clear that the credit for this work belongs to Messrs. Maskell and Parlour. In this and in thousands of other jobs, large and small, Mr. W. J. Maskell's wise and skillful hand in the administration and engineering of the projects was ever present. He contributed so very much to the Number 1 Priority Work in New Zealand—Ship Repair. More than any other person, he was responsible for the tremendous success it was. But, as far as I know, his work has not been officially recognized.

Mr. Parlour repaired to his home immediately after our conference on the *Taurus* to map his plans over a good cup of tea. The Bureau of Ships and I, acting separately, were unable to procure new coils and other necessary parts from Britain. Mr. Parlour, therefore, had the job of reinsulating all of the windings. To accomplish this, he first procured a baking oven from the New Zealand Steel Pipe and Tank Company, Ltd. The oven was a large steel shell with a door in the front. At the back a pipe was fitted for drawing a vacuum, another for admission of varnish and two additional pipes as spares. The shell was made and delivered to W. J. Parlour, Ltd. on upper Albert Street, where a base was welded to it, the shell covered with two inches of glass wool and the glass wool covered with sheet metal. Electric heating elements (12 KW) were installed in the base. A vacuum pump was obtained from a milking machine concern. The next step was to install a large steel tray in the center to run on ball races.

Mr. Parlour indoctrinated 38 men in specific tasks for the project. His concept of the baking oven proved to be a real success. Our U. S. Army and Navy units placed transportation and crane facilities at the disposal of Mr. Parlour. Although we were confident of the outcome, one more hurdle had to be overcome before we could spend more Reverse Lend-Lease money. That was to satisfy the New Zealand Treasury when they called long distance from Wellington. Mr. Parlour squashed them with his "You pay the men, I want to get on with work—so much for the red tape!"

A hole was burned in the side of the *Taurus* and a gangway equipped with rollers built from a wooden platform around the propulsion motor to the pier. A number of boxes were built to transport parts from the ship to the shop and return. The woodwork was done by R. S. Knox and Company, Ltd.

Each part of the propulsion motor, whether large or small, was numbered and a record made of its removal. This bookkeeping by Mr. Parlour was, in itself, something which accountants, I believe, would consider an accomplishment. The coil windings were put in boxes and rolled from the platform at the propulsion motor out on the

Fig. 1—A coil ready for removal from propulsion motor of USS *Taurus*.

gangway to waiting trucks to take them to the shop. Removal of the deteriorated insulation on the coils was no easy task. Knives, scrapers, wire brushes and wire brushes in the chucks of hand drills were used at first, but with little success. In the meanwhile, local chemists advised that vats should be made and provided with heaters and that they would furnish a solution to be placed therein which would expeditiously remove the insulation. This method proved to be successful.

Work proceeded around the clock for 42 days. Improvisation continued. Hundreds of sheets of insulation were cut on a band saw in much the same fashion as cloth is cut in a clothing factory. A jig was made so that coils could be bolted therein to keep their shape while being varnished. The mechanics would open the baking oven door, put the coils in the sliding tray, secure the door, turn on the heat, draw down on the vacuum pump for a specified length of time, then close the valve in the vacuum pipe line and open the valve in the other pipe for the introduction of varnish. The timing of these operations was carried out with the utmost precision. Other groups were busy with reinsulating, repair, replacement and assembly. As all parts, down to the last bolt and nut were tallied, the bookkeping extended to renewals. Every facet of the work was checked to the minutest detail. One factor, always uppermost, in planning, work, supervision and inspection was the close tolerance required.

The shop work, except for a few minor items, was finished on the 35th day. The coils and other parts were taken to the pier and rolled along the gangway to the motor platform. The rotor spider was turned after each item, large or small, was inserted or installed. Each item, each bolt, nut, pin and connector was checked against the bookkeeping tally.

On the 38th day, at 1130, the task was completed, the rotor turned, inspections completed and the motor cleaned again with a vacuum cleaner. Every item had been checked off the

Fig. 2—Mr. Harry Williams numbering a part.

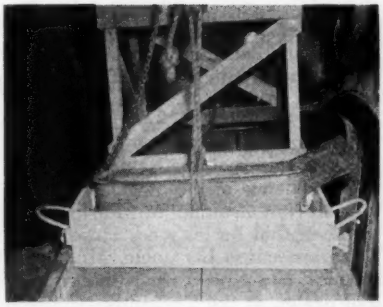


Fig. 3—Method of handling coils.

Fig. 5– Mr. Rex Steele at the Baking Oven.

Fig. 4—Pole pieces stripped of damaged insulation.

Fig. 6—Insulating some of the coils.

tally and its whereabouts known. Everyone connected with the work was tense and tired from many long and anxious hours. It was with a feeling of accomplishment we left the motor room to eat lunch together. Even the special civilian security watch joined us. This was the first time since the work started that it was not under surveillance. Who could do any harm now?

Upon our return from lunch, Captain Drake of the *Taurus*, his engineering complement and nearly all of his officers joined us to witness the test. Mr. Parlour looked happy. He said afterwards that a feeling of real satisfaction flowed down his back as the switch for the high voltage excitation current was thrown. His work was the largest job of its nature undertaken in New Zealand. The motor started. Then —a sudden flash and a deafening explosion. The motor stopped.

A search revealed a piece of steel which had cut in and grounded the 3000-volt windings. How did the steel get there? It is a mystery. The investigation made immediately and subsequent events have not provided the slightest clue.

The electricians megger-tested the motor. Mr. Parlour recommended that the motor be started again. All was well this time. The men went to work

Fig. 7—Mr. W. J. Parlour inspecting the motor after assembly just before the trial run.

again around the clock to repair the damage. Meanwhile, the ship was loaded with beef. She had a trial trip for one whole day off Auckland Harbor. The *Taurus* left at her scheduled time of departure on the 42nd day. Mr. Parlour stayed with her as she left the harbor and returned on the pilot boat with Captain Burgess, port pilot.

We watched the *Taurus* through binoculars until she was out of sight. The remainder of her Navy life proved the excellence of the biggest job of its kind in New Zealand. Mr. Parlour told me then that he felt very close to the *Taurus* because his uncle, Mr. G. W. Parlour, had played a part in her original design at the Thompson-Houston Company in Rugby, England.

When I expressed the appreciation of the U. S. Navy to Mr. Maskell, he grinned and pointed to Mr. Parlour. As I started to address Mr. Parlour he laid his hands on the shoulders of Mr. Rex Steele, his shop foreman, and Mr. Harry Williams, his outside foreman, and said "To them and their men."

HEAT EXCHANGERS FOR OIL ENGINES

ACKNOWLEDGEMENT

This article, written by A. E. UPTON, a director of Serck Radiators, Ltd., Birmingham, was published in the April 1954 issue of "The British Motor Ship." It is an extract of a paper which the author read at a meeting of the Institute of Marine Engineers.

There are, in marine applications, tubular heat exchangers for (a) engine coolants, (b) lubricating oil, and (c) pressure-charge air. The two former are necessary because during the process of converting the heat into mechanical energy the ratio of work obtained to heat input has a limiting value; the remaining heat must be rejected in the exhaust gas at the end of each working cycle. Pressure-charge air coolers materially increase the output of an engine without increasing the average combustion temperature or the heat to the jackets, etc.

The exhaust-gas boiler and other heat-recovery equipment are not included because their performance should only be related to the overall fuel utilization of the vessel.

Regarding temperatures, tests carried out at Manchester University showed that by raising the jacket outlet from 77° F. to 185° F., the fuel consumption was decreased by approximately 8%, while the friction in the engine was also reduced. Tests have also shown that by raising the water temperature from 75° F. to 175° F. at constant engine speed the amount of heat transfer to the cylinder walls was reduced from 26% to 20% of the heat in the fuel. High water temperatures in themselves are not harmful provided the corresponding metal temperatures in the liners are maintained in the region of 200-230° F. and adequate lubrication is not destroyed.

Tests on high-sped Diesel engines show that a lower percentage of heat is rejected to the coolant as the b.m.e.p. of an engine is increased. From a medium-speed high-duty engine at 60 b.m.e.p. it was 36% of the heat in the fuel; at 120 b.m.e.p. it was 29%, while for a larger but slower-speed engine the heat rejected was 25%, and at 100 b.m.e.p. only 19%. Table 1 includes typical temperature and circulation rates for the coolants.

TABLE 1.

Speed range, r.p.m.	Low speed 90-200	Medium speed 250-750	High speed 1.000-2,000
Heat distribution, B.Th.U./b.h.p./hr.			
Jackets and covers	1,100-1,500	2,000-2,300	2,500
Pistons	300-400	450-500	—
Lubricating oil	90-120	130-170	200-250
Circulation rates, gal./b.h.p./hr.			
Fresh water to jackets and covers	5.5-7.5	13-15	16
Fresh water to pistons	1.5-2.0	3.0-4.0	—
Lubricating oil	1.3-2.0	2.0-2.5	3.0-4.0
Temperatures, degs. F.			
Jackets and covers / Pistons	120/130	140/150	160/180
Lubricating oil	120/130	130/140	140/160

Notes—1. For high speed engines, circulation rates may be higher in certain types.
2. American engines are usually run at substantially higher temperatures.
3. Doxford engines operate at 135/150 deg. F. for fresh water and 160 deg. F. from pistons.
4. Where pistons are oil cooled, circulation is two or three times the normal lubricating oil rate.

The closed fresh-water systems of cooling with the use of a tubular heat exchanger is now widely adopted because it eliminates the risk of scale and sludge deposits; it permits the system to be operated at the best temperatures with a close temperature gradient across the engine, independent of the sea-water temperature.

The system now favored for some main propulsion sets and most of the medium- and high-speed installations is the parallel circuit, where a pump draws cooled water from a heat exchanger and discharges through the engine and back to the heat exchanger. A small header tank to accommodate the expansion of the water (about 10% by volume) provides against casual leakage and is connected by a small-bore pipe to a point nearest to the pump suction. The parallel system is suitable for installations without headroom, for the tank can be sited with its water level just above the highest outlet point from the engine.

Fig. 1 shows the parallel system and also how three different builders place the four principal components—engine, pump, heat exchanger and header tank—in relation to each other. A Kincaid-B and W. system arranges the heat exchanger on the freshwater-pump discharge; the water, after passing through the engine, returns to the pump suction; the header tank is connected to the pump suction on the engine outlet. Under running conditions this system puts the highest pressure on the heat exchanger, so in the case of a tube failure the fresh water would leak to sea; although this guards against contamination, there is a risk of losing water, so an alarm in the header tank is sometimes fitted.

A Sulzer arrangement provides for the heat exchanger on the fresh-water-pump suction, the engine being

on the pump discharge, the water from the engine circulating back to the heat exchanger. The header tank is connected by a small-bore pipe to a point nearest the pump suction. To avoid risk of surge and depression at the pump suction, the pipe should be of ample bore, of the shortest length possible and free from awkward bends and pockets.

The heat exchangers should also be designed for high flow rates with baffles and tube pitch which will ensure low pressure loss over long periods between cleaning. The system is suitable for the highest temperatures as the pump deals with cooled water. In case of tube failure there would be no loss of water; on the other hand, the tank would fill and overflow, denoting the condition; there would, however, be some contamination. At all speeds the engine is under the highest pressure in the circuit.

The Doxford arrangement differs from the other two because the distilled water tank is below the engine, from which a pump draws and discharges through a heat exchanger to the engine. The outlets from the engine flow into a vented hopper and gravitate to the distilled water tank for recirculation. Under running conditions the pressure in the distilled-water heat exchanger is greater than the sea water.

Tubular liquid/liquid exchangers, in which the primary fluid flows outside the tubes, are the types most used for

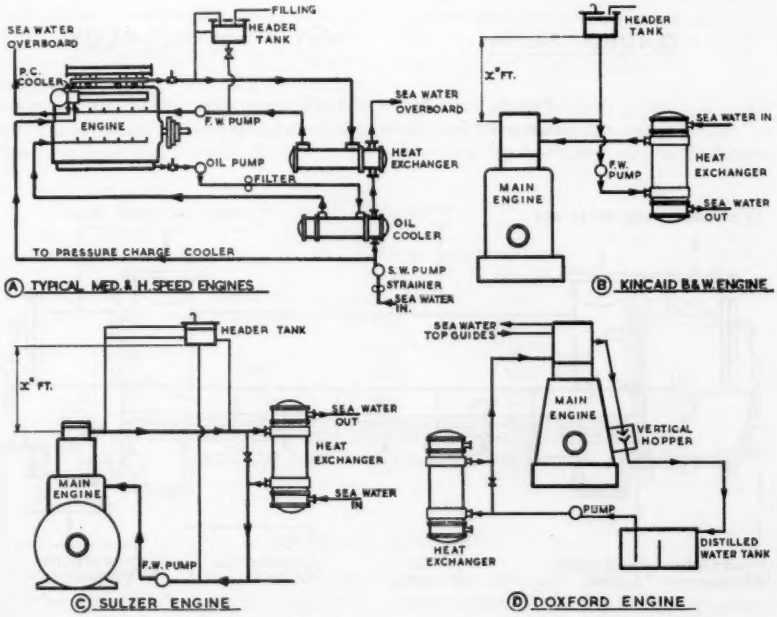


Fig. 1. Four examples of water coolant systems showing the relationship between engine, pump, heat exchanger and header tank.

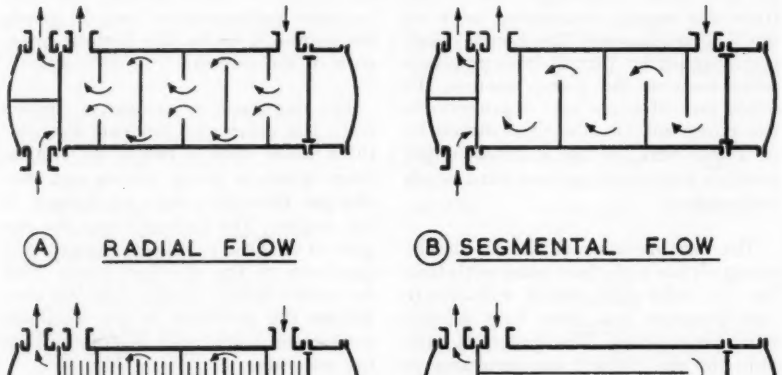


Fig. 2. Four types of baffle arrangement used in tubular heat exchangers.

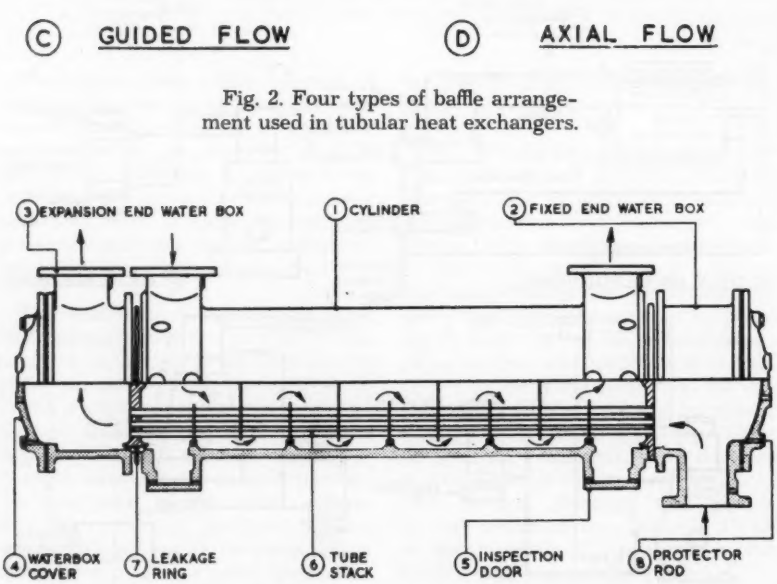


Fig. 3. Marine-type tubular heat exchanger showing distribution belts, inspection doors and removable covers in the water boxes.

marine purposes because they are the ideal shape to withstand pressure. Their form permits flexibility in design; they are reliable in operation, easy to service and overhaul, and are low in first cost.

Fig. 2 shows four types of baffle arrangement in fresh-water heat exchangers; the radial-flow arrangement (A) ensures that the fluid flows radially inward and outward at right angles to the tubes for the greatest percentage of the swept surface, an important factor in heat transfer. The flow path is also relatively consistent between the outer and inner tube rows. It is important to minimize leakage past the large baffles; for this reason sealing rings (Fig. 3) are fitted.

The segmental flow arrangement (B) demands close attention to the tube layout because the tube lanes are not of equal length across the diameter of the tube stack and at right angles to flow. Compared with the radialflow designs, less baffles are required for the same mass flow, which means there is less right-angle flow, while there is greater tendency for side leakage.

The guided flow (C) is primarily used for oil coolers to achieve right-angle flow and provide secondary surface. Axial flow (D) is used only in special conditions where there is considerable mass flow and very close temperatures between outlet fresh water and inlet sea water, and where it is desirable to have extremely low pressure loss.

Table II shows the effect of the tube diameter on matrix density for a constant-pitch ratio of 1.25:1, and the relative heat transfer.

Fig. 2 (c) shows the guided-flow oil cooler, designed to obtain the maximum right-angle flow and, at the same time, provide an amount of secondary surface where the metal temperatures and the partial heat-transfer coefficients permit high rating.

Tube diameters and pitch ratios for oil coolers are of the same order as those for fresh-water heat exchangers.

TABLE II.

O.D. of tube, in.	Relative surface area	Relative heat transfer		Oil over tubes, per cent
		Water through tubes, per cent	Water over tubes, per cent	
1	1.00	100	100	100
¾	1.33	141	150	154
9/16	1.78	199	224	237
7/16	2.28	270	318	346
¼	4.00	528	698	800

THE CHARGE AIR COOLER

Compressing the air in an engine cylinder raises the initial absolute temperature nearly threefold before any of the heat in the fuel is released, so, when an engine is fitted with a pressure charger which raises the temperature of the air in the cylinder, the whole cycle temperature is raised by a corresponding amount and it is essential to cool the air, particularly

when high pressure-charging is used. The value of cooling the air after compression in the charger as a means of getting increased power is worth while, particularly when there is an ample supply of water available, as in the case of marine applications.

Charge air cooling can increase the output of a pressure-charged engine something like 10% without raising the maximum cylinder temperatures to any appreciable degree. There is, however, little gained by using coolers for boost pressures less than 3½ lb., for the advantage due to the reduction in air temperature is just about balanced by the effect of the back pressure of the cooler.

Fig. 4 shows the limiting lines of economical cooling of charge air. It is possible with coolers of reasonable size and weight to cool the air to within 15° of the sea-water temperature. B.S.I. 649 Standards rate a normally aspirated engine on the basis of 85° F. ambient and 14.45 lb. per sq. in. absolute, the engine being derated 3% for each 10° rise above the standard temperature.

Fin and tube is the usual form of surface used in charge air coolers, although there are designs where only

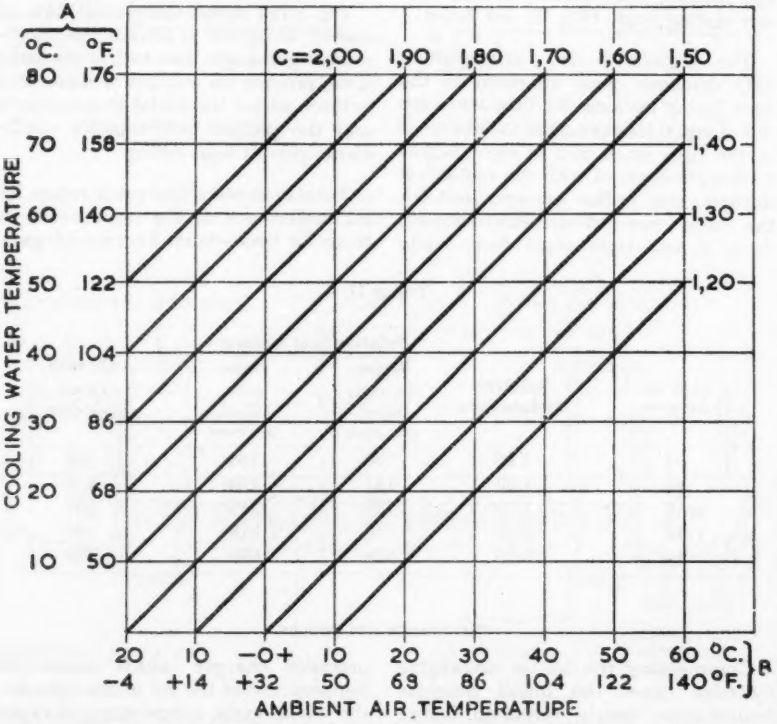


Fig. 4. General limiting lines of economical cooling of charge air for various compression ratios.

primary surface is adopted. All forms of secondary surface benefit from turbulence promoters on the air side and, within the range of normal secondary surface types using tubes of average form, the surface per unit volume is nearly independent of the tube diameter, hence a reasonable diameter can be accepted.

The ribbon tube cooler has individual tubes expanded into tube plates fitted with separate water boxes; as individual tubes, they are not always easy to support against vibration, while the ribbon which forms the fin is not coincident in the direction of air flow, which makes the cleaning of the air side more difficult.

With the matrix type of cooler having continuous-plate fins, the surface per unit volume is increased; at the same time, the continuous fins support adjacent tubes. The fin plates are straight on the leading and trailing edges to enable them to be easily cleaned.

COMPRESSIBLE FLOW OF A SEMI-PERFECT GAS

ACKNOWLEDGEMENT

The 18 June, 1954, issue of "Engineering" carried this article, which was written by Dr. D. B. Spalding, of the Department of Engineering, University of Cambridge.

To facilitate the calculation of the compressible flow of a gas it has been common to assume the gas to be perfect, that is to obey the equations

$$p\ v = RT \quad . \quad . \quad . \quad (1)$$

and

$$c_p = \text{const.} \quad . \quad . \quad . \quad (2)$$

where p = pressure, v = specific volume, R = gas constant, T = absolute temperature, and c_p = specific heat at constant pressure. Air, the substance of chief practical interest, obeys the first equation very closely, but not the second; for c_p increases with temperature from 0.24 B.T.U. per lb. per deg. F. at room temperature to over 0.3 B.T.U. per lb. per deg. F. at high temperatures. It is therefore not permissible to assume that the ratio of the specific heats is constant. Yet when this ratio, k, varies with temperature, the equations of motion cannot be integrated.

In practice the variation of k with temperature is neglected. This permits the derivation of explicit expressions for, for example, the pressure ratio in an isentropic expansion, or the change of density in a shock wave. Many such expressions have been evaluated and tabulated, for example, by Shapiro, Hawthorne and Edelman (1947)* and by Keenan and Kaye (1948)† and most calculations are carried out with the aid of such tables.

The error involved in assuming that k is constant is not significant when the temperature range of the process is small, but may become important at high Mach numbers, where a method of dealing with variable k is desirable. The present article describes a graphical way of doing this. This method has, in addition, the advantages of reduced intermediate computation, of clearly representing the physical considerations involved, and of easy use; it suffers, however, from the limitation on accuracy common to all graphical procedures.

*A. H. Shapiro, W. R. Hawthorne & G. M. Edelman, *Jl. Appl. Mech.* vol. 19, page A317, (1947).

†J. H. Keenan & J. Kaye, *Gas Tables*, Wiley, 1948.

TEMPERATURE-VELOCITY DIAGRAM

Compressible-flow phenomena will be represented on a graph of temperature versus velocity, both plotted logarithmically. Discussion will be restricted to gases which obey equation (1) although it is not necessary to make the further restriction that they also obey equation (2).

Graphs are of great convenience in representing the thermodynamic properties of a pure substance, because two properties suffice to determine the state of the substance in the absence of effects due to motion, gravity, capillarity, electricity and magnetism; each point on the graph therefore can

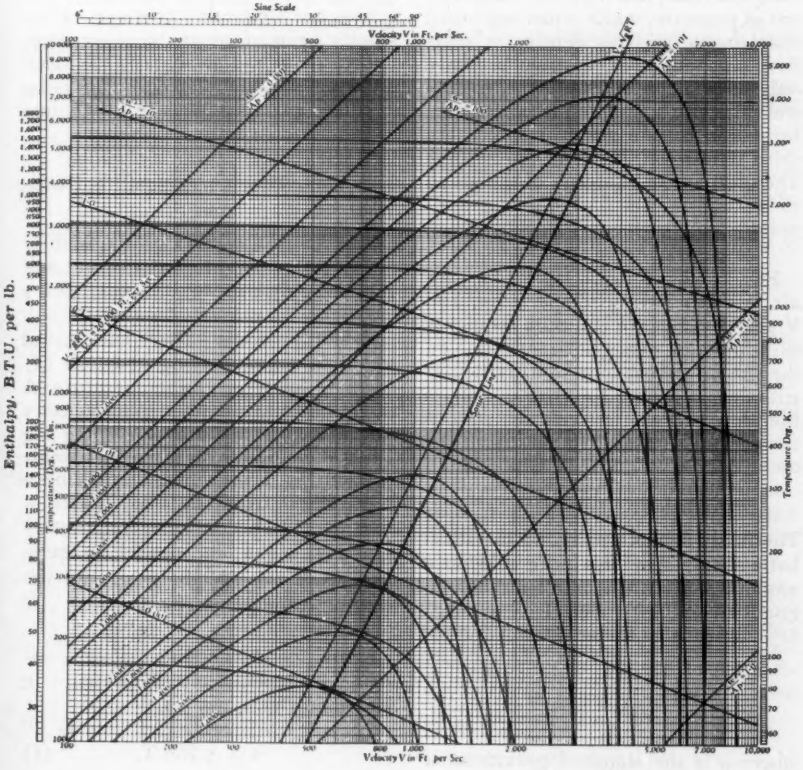


Fig. 1. Since the enthalpy of a semi-perfect gas is independent of pressure, valuable information regarding gases in motion can be obtained from a two co-ordinate graph. The gases are assumed to obey the equation $p\,v = RT$ but not c_p = constant. On this compressible-flow chart for air a number of relationships have been plotted with reference to logarithmic co-ordinates of temperature and velocity.

represent a state. Here we are concerned with a pure substance in motion, so that three properties must be prescribed, such as pressure, temperature and velocity, to determine the state completely; such a situation calls for a three-dimensional graph. However, it is a characteristic of substances obeying equation (1) that enthalpy and internal energy are pure temperature functions, i.e., they are independent of pressure; while other important magnitudes, such as density or mass flow per unit area, involve pressure only as a simple multiplier. It is possible therefore to obtain important information from a graph in which the third dimension, pressure, is omitted. The ordinate and abscissa of the graph to be used are the logarithms of temperature and velocity respectively.

Fig. 1 shows a log T/log V chart for air, T representing temperature, and V velocity. Since h is a pure temperature function, every horizontal line on the graph corresponds to a particular enthalpy; a vertical enthalpy scale is therefore drawn as well as various temperature scales. The nature of the other curves will now be explained.

Adiabatic flow.—The First Law of Thermodynamics, applied to the adiabatic steady flow of a pure substance without shaft work or effects due to gravity, capillarity, electricity or magnetism, leads to the equation

$$h + \frac{V^2}{2gJ} = h_0, \quad . \quad . \quad (3)$$

where g is the standard gravitational acceleration, J the mechanical equivalent of heat, and h_0 the stagnation enthalpy, i.e., the enthalpy when the stream is brought to rest.

Curves of equation (3) are plotted on the log T/log V chart for various values of h_0, which is represented in each case by the left-hand intersection of the curve with the h-scale; for on the left V is very small so that h and h_0 are practically identical, and the curves are horizontal. The curves droop downwards to the right at the high velocities, for there the enthalpy decreases considerably. Velocity can be read from the logarithmic scales at the bottom and top of the chart. The curves are all similar in shape: if the specific heats of the gas were constant, the curves would be actually identical, differing only in displacement along a direction parallel to the line

$T = \frac{V^2}{gR}$. They correspond to Fanno curves (Stodola, 1927) on the Mollier (enthalpy-entropy) diagram, and will here be called energy lines.

Sonic Velocity.—The velocity of sound in a gas obeying equation (1) depends solely on the temperature. A single line representing sonic velocity can therefore be drawn on the log T/log V diagram; this is marked "sonic line" in Fig. 1, for which all data have been taken from the *Gas Tables* of Keenan and Kaye. This line is very nearly straight, and would be quite straight if the specific heats did not vary with temperature.

It may be shown that the sonic velocity, a, depends on tempertaure in accordance with the law

$$a = \sqrt{k\,R\,T}, \quad . \quad . \quad (4)$$

where k, is the ratio of specific heats at the temperature T. The ratio of the actual velocity to the sonic velocity is known as the Mach number M.

$$\frac{V}{a} = M. \quad . \quad . \quad (5)$$

DIRECT READING OF MACH NUMBERS

Fig. 2 shows how M can be obtained directly from the log T/log V chart. If A represents the state of the gas, the length AB represents log V − log a; when stepped off along an appropriate logarithmic scale, such as the horizontal velocity scale, from the point marked 1 (or 10, 100, etc.), this distance yields Mach number directly. The reason for plotting log V instead of V now becomes clear; the chart avoids subsequent use of the slide-rule by itself incorporating the principles of the slide-rule. It is not usually hard to decide whether AB should be stepped off to the left or to the right. The sonic line divides the chart into two regions: subsonic to the left (M<1); supersonic on the right (M>1).

The pressure line.—If the flow along a duct is steady, the law of conservation of matter leads to the continuity equation

$$\frac{w}{A} = \frac{V}{v}, \quad . \quad . \quad (6)$$

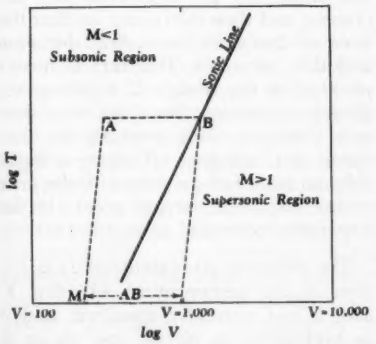


Fig. 2. The Mach number for any given gas velocity can be obtained directly from the chart by measuring on the log V scale the length AB, where A represents the state of the gas and B the sonic velocity at the same temperature.

where w = mass flow, and A = cross-sectional area of duct.
Substituting in (6) from (1), we obtain

$$\frac{w}{Ap} = \frac{V}{RT}. \quad . \quad . \quad (7)$$

Since T is a unique function of enthalpy, curves of equation (7) can be drawn for various values of $\frac{w}{Ap}$. They are of course straight lines at an angle of 45 deg. and are drawn in Fig. 1 for $\frac{w}{Ap} = 1, 0.1$, etc., lb. (mass) per sec., per lb. (force). They are referred to as pressure lines.

The pressure lines may be used to evaluate $\frac{w}{A}$ if the local pressure is known. The distance between the state point and the pressure line is stepped off on a logarithmic scale from the point 1, to the left or right according to the position of the point relative to the line.

Reversible adiabatic flow.—The entropy s of a pure substance is related to the enthalpy and pressure by the equation

$$T\,ds = dh - v\,dp. \quad . \quad (8)$$

This is a consequence of the Second Law of Thermodynamics. In a reversible adiabatic process, $ds = 0$. Substituting in (8) for v with $ds = 0$ from (1) and integrating, we obtain

$$\int_1^2 \frac{dh}{RT} = \log_e\left(\frac{p_2}{p_1}\right). \quad . \quad (9)$$

The integral on the left-hand side has been tabulated for air by Keenan and Kaye (1948). From their data it is possible at every temperature level to step off the horizontal distance corresponding to this integral from any

pressure line. Joining these points results in a line which will be called the isentropic. All points on this line are at a horizontal distance from the pressure line corresponding to the logarithm of the ratio of the actual pressure to some other pressure; this other pressure is that prevailing at the intersection of pressure line and isentropic. The isentropics are drawn in Fig. 1 so that they intersect the pressure lines at T = 492 deg. F. abs. (0 deg. C.). In Fig. 3, illustrating this, the length AB gives the ratio of the initial and final pressures in an isentropic expansion to 492 deg. F. abs. from any point at the temperature of A and B, for example that along the energy line connecting C and D; dividers and a logarithmic scale give this ratio numerically. The choice of 492 deg. is arbitrary, the pressure attained if an isentropic expansion reduces the temperature to 492 deg. will be given the symbol p_s. The isentropics are nearly straight, and would be quite straight if the specific heats were constant, i.e., for a perfect gas.

NOZZLE DESIGN

The horizontal distance between an energy line and the isentropic is significant. In Fig. 3, A B represents $\frac{p}{p_s}$ as we have seen, while B C represents $\frac{w}{Ap}$. The distance A C therefore represents $\frac{w}{Ap_s}$. The constant value of $\frac{w}{Ap_s}$ appropriate to each isentropic is marked on Fig. 1. Since p_s is a constant for a given expansion. A C is proportional to the mass flow per unit area. It is seen that the horizontal distance has a maximum value A′C′, which occurs at the intersection of the energy line with the sonic line. This means that as the gas expands isentropically from high pressure to low the mass flow per unit area first increases and then decreases, so that the area of the duct must first decrease and then increase. This fact is incorporated in the design of convergent-divergent nozzles. Since the mass flow w is constant along a nozzle the distance A C stepped off along a logarithmic scale can give directly the area of the nozzle at various points in the expansion provided p_s is known.

Fig. 3. Isentropic lines enable reversible adiabatic flows to be investigated and information regarding the design of convergent-divergent nozzles may, for example, be obtained.

The pressure after isentropic expansion to the temperature 492 deg. F. abs. is not normally specified, and it is preferable to obtain the value of $\frac{w}{Ap_0}$, where p_0 is the stagnation pressure. For any point along the isentropic expansion A B in Fig. 4 the length C D represents $\frac{p_0}{p_s}$, so that $\frac{w}{Ap_0}$ is giv-

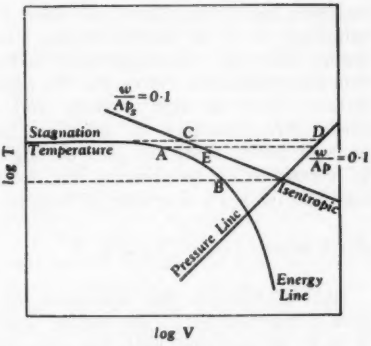


Fig. 4. For any point in the isentropic expansion AB, the mass flow per unit area with a given stagnation pressure can be found from the length AE and CD.

en by A E + C D. This length may easily be stepped off along a logarithmic scale by means of dividers and the mass flow per unit area with a given stagnation pressure can be found for any point of the expansion.

The pressure ratio $\frac{p}{p_0}$ at any point of the expansion is found by stepping off the distance C D − E.F. Care is needed in deciding whether to step off to the left or to the right of the 1 of the logarithmic scle, but physical considerations usually make this clear.

Momentum lines.—Consideration of momentum shows that, for flow without friction in a duct of constant cross-section,

$$p + \frac{V_2}{g} = \text{const.} \quad . \quad (10)$$

Introducing the gas law (1) and the continuity equation (6), with $w =$ const., we obtain

$$\frac{R\,T}{V} + \frac{V}{g} = \text{const.} \quad . \quad (11)$$

ADDITION OF HEAT TO GAS FLOW IN PIPES

Such relations between V and T have been drawn on the log T/log V chart, Fig. 1, for various values of the constant. They correspond to a family of Rayleigh lines (Stodola, 1927) on a Mollier diagram; each line represents the possible states when heat is added to air flowing without friction in a parallel pipe. The lines show the usual characteristics of Rayleigh lines. Starting at the left-hand end, velocity and temperature at first increase together; a maximum temperature is reached when the velocity is equal to $\sqrt{g\,R\,T}$, and the temperature diminishes thereafter. At the intersection with the sonic line the slope is the same as that of the energy curve at that point and of the isentropics at that temperature. At the left-hand end the curves are almost parallel to the pres-

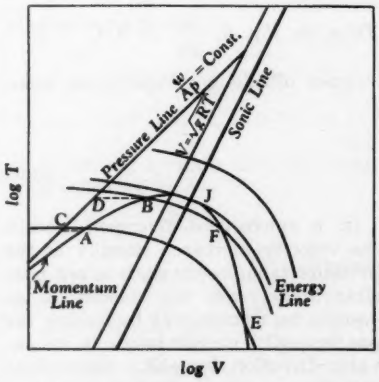


Fig. 5. The change from A to B along a momentum line represents the addition of heat to a flowing gas in a frictionless parallel pipe.

sure lines; at the right-hand end the curves slope steeply downwards. The curves will be referred to as momentum lines. They are all identical in shape, differing only in their displacement along the line $V = \sqrt{g R T}$.

Fig. 5 illustrates the addition of heat to a flowing gas in a frictionless parallel pipe, by the change from A to B along a momentum line. The quantity of heat added is measured by the difference of stagnation enthalpy corresponding to the energy curves which pass through A and B. Fig. 5 shows that there is a maximum to the amount of heat which can be added, for energy lines above that passing through the point J do not intersect the momentum line at all. Since the point of tangency, J, is on the sonic line, this means that the maximum heat addition produces sonic velocity at the pipe outlet. Flow through a duct under these circumstances is said to be choked, for no more can pass through. It is interesting to observe that heat addition causes a decrease of temperature when $T < \frac{V_2}{g R} < k T$.

Heat addition in the supersonic region is represented by the change from E to F. In this case both the velocity and Mach number fall, but the temperature rises. Once again heat addition reaches a maximum with the attainment of sonic velocity.

PRESSURE CHANGES RESULTING FROM HEAT ADDITION

Pressure changes result from heat addition. These may be measured on the compressible-flow chart by the change of horizontal distance from a pressure line, since $\frac{w}{A}$ is constant. Thus, in Fig. 5, $\frac{p_A}{p_B}$ is A C − B D stepped off along a logarithmic scale. In subsonic flow heat addition causes a fall of pressure; in supersonic flow it causes a rise of pressure. Cooling of course has the opposite effects. There are also changes of the same sign in stagnation pressure, which may be measured by the procedure outlined above. Heating always reduces the stagnation pressure; cooling always increases it.

SHOCK WAVES

In a convergent-divergent nozzle, the velocity increases steadily as the pressure falls; however, it is not possible to decrease the velocity in an equally continuous way by leading the gas through a similar nozzle in the reverse direction. Instead a discontinuous change occurs which is known as a shock wave. Downstream of the shock the velocity is subsonic, and the pressure is greater than upstream; but the entropy is found to have increased, a sign that the process is irreversible.

Shock waves are of such small thickness that heat losses, wall friction and changes in duct cross-section may be neglected. It follows that equations (3) and (10) both hold: momentum and energy are conserved, although there is a transformation from kinetic to thermal energy. The representation of shock waves on the log T/log V chart will now be discussed.

The Normal Shock.—Fig. 5 shows that, in general, a given pair of momentum and energy lines intersect at two points. Thus two states are possible for a stream of fluid of given stagnation enthalpy and momentum. These states are those which exist on either side of the discontinuous change from supersonic to subsonic velocity which is known as a shock wave.

In Fig. 6 the points A and B represent states before and after a normal shock, respectively. It is usually desired to find the conditions downstream of the shock, the conditions upstream being specified. The downstream velocity V_2 may be read directly from the horizontal velocity scale. From the continuity equation, the specific volumes are in the same ratio as the velocities; the distance A E along a logarithmic scale gives this ratio. The Mach numbers M_1 and M_2 are measured by A C and B D.

Since $\frac{w}{A}$ has the same value before and after the shock, the pressure ratio $\frac{p_2}{p_1}$ is given by the distance (B G − A F), which may be marked off with dividers along a logarithmic scale; $\frac{p_2}{p_1}$ is, of course, always greater than unity. However, there is always a loss of stagnation pressure; in terms of $\frac{p_{02}}{p_{01}}$, this is measured by the difference between the lengths A H and B I which represent the distances to an isentropic line. When A and B are very close together, which means that the Mach numbers are close to unity, the energy, momentum and isentropic lines have nearly equal slopes; this means that the loss of stagnation pressure in such a shock is very small. The temperature after the shock can, of course, be read directly from the vertical scale.

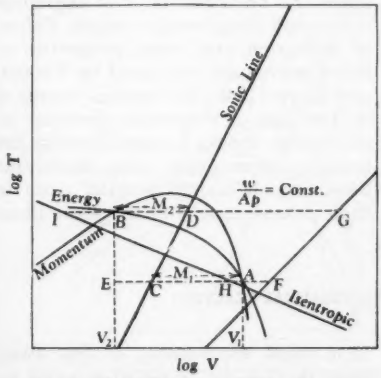


Fig. 6. The points A and B represent states before and after normal shock. Given the upstream conditions those downstream may be found.

The Oblique Shock.—When a supersonic gas stream is deflected, for example by solid boundaries, in a direction which causes a pressure rise, a shock wave is formed along a plane which is oblique to the direction of the stream; Fig. 7 illustrates this. The tangential component of velocity parallel to the plane of the wave is unaltered, but the normal component is changed in the way indicated in the foregoing section.

The velocities and angles are related by the expressions

$$\left.\begin{aligned} &\frac{V_x}{V_1}=\frac{M_x}{M_1}=\sin\alpha_1;\ \frac{V_y}{V_2}=\frac{M_y}{M_2}=\sin\alpha_2 \\ &V_1\cos\alpha_1=V_2\cos\alpha_2;\ \omega=\alpha_1-\alpha_2 \end{aligned}\right\} \quad . \quad . \quad . \quad (12)$$

in which the symbols have the meanings indicated in Fig. 7.

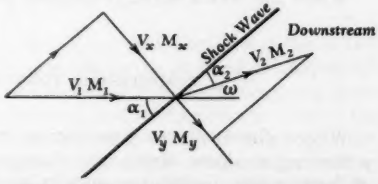


Fig. 7. This diagram illustrates the oblique shock which occurs when a supersonic gas stream is deflected.

LOG-SIN SCALE ON CHART FOR CALCULATING ANGLES

Referring to Fig. 8 we consider a gas stream of condition indicated by point A which enters a shock wave at an angle α_1. The stream Mach number M_1 is given by the distance A C on a logarithmic scale. If B represents the component relative to the shock, the normal Mach number M_x is represented by B C. The distance A B represents $\frac{M_x}{M_1}$ and so is a measure of sin α_1; a scale of log sin α is provided on the compressible-flow chart (Fig. 1) so that α_1 can be immediately determined by means of dividers; B, of course, is on an energy line of lower stagnation enthalpy than A, but at the same actual enthalpy.

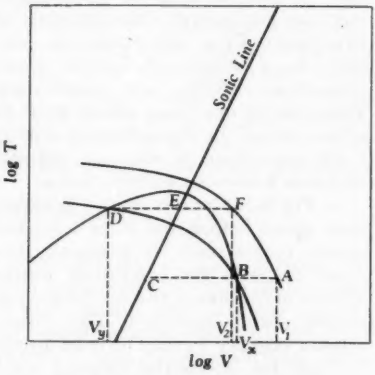


Fig. 8. The point A represents the condition of a gas before entering a shock wave at an angle. F gives the downstream state of the gas.

Conditions downstream of the shock are represented by the point D which lies on the energy and momentum lines which also pass through B; D E represents the downstream normal Mach number M_1 which is of course less than unity. In the case illustrated the downstream resultant Mach number M_2, represented by E F, is greater than unity, but it is easy to envisage shocks for which F lies to the left of the sonic line. The stream after the shock is represented by F; it lies on the original energy line and is at the same enthalpy level as D. the length D F represents sin α_2. The angle α_2 can be obtained from the log-sin scale and the deflection w is obtained by subtracting α_1 from α_2.

When the shock wave is inclined to the direction of flow at an angle close to 90 deg., the deflection is correspondingly slight. In this case it is difficult to obtain accurate values of $\alpha_2 - \alpha_1$ from the log T/log V chart, and an analytical method is preferable. Such a method is also without serious error since the variation of k is negligible over small temperature ranges. Values of deflection and other properties of shock waves are tabulated by Keenan and Kaye (1948) for various values of k. The loss of stagnation pressure in such weak shocks is small because the energy, momentum and isentropic lines are all nearly parallel close to their intersection with the sonic lines.

COMPRESSIBLE FLOW WITH CHEMICAL REACTION

Where chemical reaction occurs in a flowing medium, there are changes of both mean molecular weight and temperature; both changes affect the specific volume of the fluid. If the specific volume increases on combustion, as is usual, the velocity of flow away from the region of reaction must be greater than the velocity of flow into it. Chemical reaction therefore modifies the pattern of flow.

A reacting gas is not a pure substance in the thermodynamic sense, and a large number of independent properties must be specified, in general, to define its state. Fortunately, however, the region in which reaction actually takes place is normally of small extent compared with the regions filled by totally burned or totally unburned gas, so that only the initial and final mixtures are of significant effect on the flow, the important characteristics of each mixture being the mean molecular weight, and the enthalpy-temperature relation.

As a first approximation, the reactants and combustion products of a reaction can be regarded as having equal molecular weights, and the enthalpy-temperature relations can be regarded as identical except for a constant which is of course the enthalpy change of a constant-temperature reaction, i.e., the calorific value of the mixture. In this case, it is possible to replace the change of composition at constant enthalpy by a change of enthalpy at constant composition, i.e., to treat a flame as a region where a fixed amount of heat is added to a pure substance. When this is done flames can be represented on the log T/log V chart, and compressible flow phenomena can be calculated. This artifice is convenient, and does not normally lead to serious errors. Its artificial nature should however be recognized; a flame is not really a heat addition.

DEFLAGRATION

Normal Flames.—Flames have some characteristics in common with shock waves; they are effectively surfaces of discontinuity in the flow. As with shock waves, flames which are normal to the direction of flow will be considered first. Gas is supposed to flow steadily along a straight pipe; at a certain section the stagnation enthalpy is suddenly increased by a fixed amount, say from h_{01} to h_{02} in Fig. 9. The state upstream of the flame is represented by A, in the subsonic region. The state downstream must therefore be represented by B, which is also subsonic, or by C which is supersonic. The latter possibility is never realized in practice.

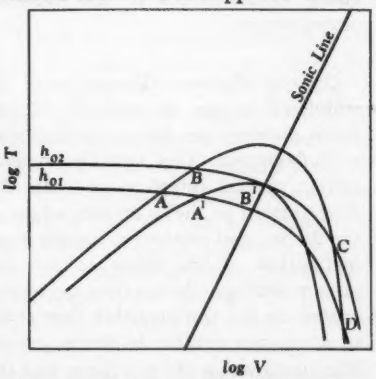


Fig. 9. Changes in density, pressure and Mach numbers across flames can also be obtained from the chart. Deflagration and detonation conditions for normal flames are represented here.

The A B type of flame is known as a deflagration. The velocity at which it travels is determined by the nature of the chemical reaction and the thermal conductivity of the gas. In laminar flow it is a constant for a given mixture and initial state.

We have seen above that there is a maximum to the amount of heat which can be added to a gas flowing at a given velocity and temperature. When the heat addition is fixed, as in a flame, there is therefore a maximum steady flame velocity. This is illustrated by the momentum line A′ B′ in Fig. 9.

Flames such as A′ B′ for which the

downstream Mach number is unity, are known as Chapman-Jouguet deflagrations (Chapman, 1899*; Jouguet, 1905, 1926†). It is interesting to consider what happens when the flame velocity exceeds that which will produce such a deflagration. There is no known interaction between the fluid dynamics and chemistry which could reduce the chemical reaction to an acceptable rate; there can therefore be no question of the flame being extinguished. The only alternative is that the flame cannot be steady.

DETONATION

If the flame forms in a stream of initially supersonic velocity, such as D in Fig. 9, the downstream conditions might be represented by C. This is, however, unknown in practice. Usually this type of flame is initiated by a shock wave, and the combined shock and flame gives a downstream condition such as that represented by B in Fig. 9. This type of flame is known as a detonation; its velocity of propagation is less dependent on the chemical properties of the gas than is the deflagration. Detonations are little understood and will not be discussed further here.

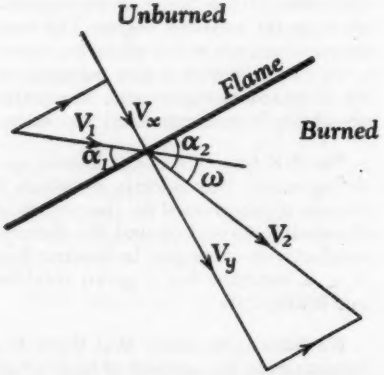


Fig. 10. Oblique flames may be investigated on the chart similarly to oblique shock waves.

Changes in density, pressure and Mach number across flames can be measured from the log T/log V chart in the manner indicated in foregoing sections. Deflagration velocities are of the order of only a few feet per second while temperature changes are of the order of 3,000 deg. F. Deflagrations are therefore represented by lengths of momentum line which are normally well to the left of the chart, in the region where the momentum lines are practically straight lines at 45 deg.; pressure and density changes in deflagrations are therefore slight, and the ratios of the velocities upstream and downstream of the flame are closely equal to the ratios of the absolute temperatures.

Oblique Flames.—Flames may be stabilized in gas streams of velocity much greater than the normal velocity of deflagration. This usually involves rather special interference with the flow pattern at the upstream edges of the flame, and elsewhere results in an inclination of the flame to the gas stream. Oblique flames may be represented on the compressible flow chart in a manner similar to shock waves. Fig. 10 shows an oblique flame and the nomenclature to be used. Whereas in a shock wave α_2 is less than α_1, in a deflagration the deflection is towards the normal.

*D. L. Chapman, *Phil. Mag.*, vol. 47 page 90 (1899).

†E. Jouguet, *Jl. Math.* page 347 (1905); *Proc. Second Int. Cong. Appl. Mech.*, page 12 (1926).

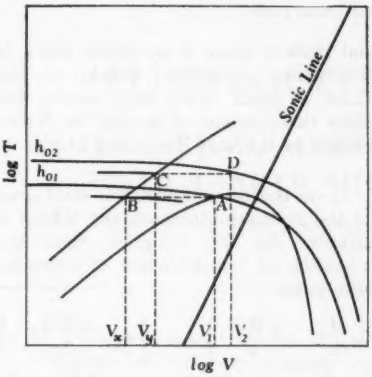


Fig. 11. The relationships found across oblique flames have applications to gas-turbine design.

Let A in Fig. 11 represent the combustible gas stream. We suppose that the normal speed of deflagration of the gas, V_x, is fixed. Then B, at the same temperature as A, represents the component of velocity normal to the flame. The distance AB therefore represents sin α_1 when measured on a logarithmic scale. B, of course, is on a lower energy line than A. If the stagnation enthalpy change $\triangle h_0$, which represents combustion, is fixed, the normal component of velocity downstream of the flame is represented by C where $\triangle h_0 = h_{0C} - h_{0B}$. If D lies on the energy line with stagnation enthalpy $h_{0A} + \triangle h_0$ and is also at the same temperature as C, the horizontal position of D gives the resultant velocity V_2 downstream of the flame. C D measures sin α_2. The deflection ω is found by subtracting α_1 from α_2. It is interesting to observe in Fig. 11 that a normal flame of velocity V_1 would have been impossible, the enthalpy change being too great for the Chapman-Jouguet condition; whereas the oblique flame is well away from this limitation.

GAS TURBINES

When the normal flame speed V_x is low, the points B and C may both lie so far to the left on the log T/log V diagram that their respective energy lines are locally horizontal. In this case the above procedure clearly leads to D being vertically above A, i.e., the resultant velocity is unchanged in magnitude ($V_2 = V_1$). This is an extreme to which practical flames approximate quite closely. Of course, $M_2 < M_1$ because the sonic velocity increases with temperature. Such flames have no change of pressure across them. The deflection ω is obtained from considerations of continuity, and is given by

$$\omega = \alpha_2 - \alpha_1 = (\lambda - 1)\ \frac{V_x}{V_1} \text{radians}, \quad (13)$$

where $\lambda = \dfrac{V_y}{V_x}$ = the temperature ratio for a constant pressure flame, which in practice is of the order of 5. In a high velocity combustion chamber, such as a gas-turbine re-heat system, $\dfrac{V_x}{V_1}$ may be of the order of $\dfrac{1}{100}$, so that deflections of only a few degrees may be met with. The flame itself makes an angle of the same order with the incident gas stream. On the log T/log V chart, λ is given by the vertical distance between AB and CD, measured on a logarithmic scale.

MIXING PROCESSES: EJECTORS

In the design of ejectors and other equipment it is often necessary to know the state of the stream formed by the complete mixing of two streams of known state. The length of duct necessary for mixing cannot be determined from thermodynamic considerations alone, but the final state can. Often one stream is supersonic and the other is sonic, and the possibility of shock waves must be considered. Two cases may be distinguished, namely, constant-pressure mixing and constant-area mixing.

In the former the cross-sectional area of the duct is assumed to be varied so that the pressure of the outgoing stream is the same as that of the incoming streams, which are always supposed to be of equal pressure. In this case the conservation of momentum requires that

$$w_1 V_1 + w_2 V_2 = (w_1 + w_2) V_3, \quad (14)$$

where subscripts 1, 2 and 3 refer to the two initial streams and the final stream respectively. The other equation determining the final state is that for the conservation of energy, namely,

$$w_1 h_{01} + w_2 h_{02} = (w_1 + w_2) h_{03}. \quad (15)$$

Equations (14) and (15) fix, respectively, the final velocity V_3, which is between V_1 and V_2, and the final energy line on the compressible-flow chart, which is between the energy lines of the initial streams. The intersection of this energy line and the vertical line for V_3 determines the final state if there is no shock wave. If supersonic velocities obtain in the duct, a shock wave may occur; the state downstream of it may be determined in the way described above.

If, on the other hand, the total area of the duct remains constant, which is simpler for the designer, then the equation of conservation of momentum runs

$$w_1\left(V_1 + \frac{g R T_1}{V_1}\right) + w_2\left(V_2 + \frac{g R T_2}{V_2}\right) = (w_1 + w_2)\left(V_3 + \frac{g R T_3}{V_3}\right), \quad (16)$$

while (15) still represents the conservation of energy in adiabatic flow. In this case therefore the momentum line of the final stream is fixed. It lies between the momentum lines of the two ingoing streams, and its intersections with the final energy line give the two possible downstream states.

Thus, whichever type of mixing is in question, the compressible-flow chart, Fig. 1, enables the state of the resulting stream to be determined. The determination of V_3 or $\left(V_3 + \frac{g R T_3}{V_3}\right)$ must be done arithmetically from the mass flows and states of the initial streams. Once the final state point has been fixed on Fig. 1 the new area or pressure, temperature and stagnation pressure can be determined in the way described above.

ELECTROLYTIC DESCALING

AN ELECTRICAL METHOD OF RUST REMOVAL FROM TANKER SHIP COMPARTMENTS

F. E. COOK, H. S. PREISER, AND J. F. MILLS

The Authors

Frank E. Cook was born in Salem, Virginia. He was educated at Roanoke College (B.S.) and at the Ohio State University receiving an MS in Chemical Engineering in 1931. He was employed for several years as a Foundry Metallurgist at the Norfolk and Western Railway Co., Roanoke, Virginia, and for a short time as an Instructor in Chemical Engineering at Ohio State University. As a Chemist for the Quartermaster Corps, U.S.A., San Antonio, Texas, 1932-39, he established a materials and food testing laboratory. He has also served as a Materials Engineer for the U. S. Maritime Commission, Washington, D. C., 1939-47 and is now Deputy Head of the Coatings and Preservation Branch, Research Division of the Bureau of Ships, Department of the Navy, Washington, D. C. He is a member of Sigma Xi, the Association of Corrosion Engineers, the American Chemical Society and the Washington Rubber Group.

Herman S. Preiser, a native New Yorker, was graduated from the New York State Maritime Academy in 1946 as a licensed Third Assistant Engineer. He received a B.S. Degree from Webb Institute of Naval Architecture and Marine Engineering in 1949. During vacations and lulls between schools and jobs, he served as a licensed engineering officer on several merchant vessels for a total period of about a year. In 1950 he entered the Department of the Navy, Bureau of Ships, and after having completed a one year engineering training course, he worked for the Preliminary Design Branch as a Naval Architect for submarines. He attended George Washington University and the University of Maryland during the evening from 1951-1953 for graduate work in electrochemistry and metallurgy. Since 1952, he has been associated with the Coatings and Preservation Branch of the Bureau as a Corrosion Engineer. He is a member of The Society of Naval Architects and Marine Engineers, The Electrochemical Society and the National Association of Corrosion Engineers. Mr. Preiser is a registered Professional Engineer in the District of Columbia.

J. F. Mills was born in Walla Walla, Washington January 23, 1901. Is a Registered Engineer in the State of Washington. Received the following degrees at Washington State College, Pullman, Washington: B.S. (1926); B.S. in Mechanical Engineering (1927); B.S. in Electrical Engineering (1927); M.S. in Mechanical Engineering (1928); Metallurgical Engineer (1935). Part time instructor in Mechanical Engineering Drawing at Washington State College, Pullman, Washington 1927-28. Assistant Design Engineer at Lamb-Grays Harbor Machine Company, Hoquiam, Washington 1928-29. Head of Metallurgical Laboratory at Puget Sound Naval Shipyard 1930-46. Head of Material Laboratories, including Chemical Laboratory, Metallurgy and Engineering Laboratory, Research and Test Engineering Laboratory, Rubber and Plastics Laboratory, and Molded Boat and Polyester Laminates Laboratory, 1946-present. National President of the National Association of Naval Technical Supervisors 1954 and President of the Puget Sound Chapter 1954.

SECTION 1—INTRODUCTION AND DISCUSSION

Application of method — In almost every engineering application involving the use of ferrous materials, the problem of rust removal is forever present. The effectiveness of the paint and preservation of steel requires a clean, rust-free surface for optimum performance. Clean rubbing surfaces between the steel components of machinery is necessary to insure its uninterrupted operation. When steel containers are reused for storing various fuels or other liquids and chemicals, often rust must be removed to prevent contamination. In the past, chemical, mechanical and thermal methods have been employed for cleaning rust from steel and in many cases they proved to be costly and not entirely effective. In recent years a great deal of effort has been expended by Government and Industry to produce an economical and efficient electrolytic descaling technique. This method is gradually receiving widespread consideration for the cleaning of relatively small objects as evidenced by several commercial processes available on the American and British markets (1).

The fact that electrolytic descaling can be accomplished by immersing small metallic articles in tanks containing the electrolyte or by immersing larger components directly in the sea or by filling the tank, cylinder or container to be cleaned with the electrolyte, allows a wide diversity in the type of equipment which can be cleaned by this process. The British Admiralty has successfully applied electrolytic descaling techniques to the cleaning of a high pressure turbine, a badly rusted internal combustion engine, boom defense equipment, a superheater header and a variety of other equipment. A summary of the British work has been effectively covered in the literature (2.)

The various electrolytic descaling processes available do not differ in their essential elements but only in minor modifications. The theory involved is relatively simple. However, the engineering necessary to apply this theory effectively to large surfaces and complex structures in situ, is a problem of considerable magnitude. This paper will be confined mainly to efforts of the Bureau of Ships to descale and clean tanker ship compartments of U. S. Naval vessels.

Description of the process—The ability of a properly applied electric current to remove rust from metals has been known for the past several decades. Numerous patents have been filed describing different ways of derusting and descaling metals by electric means (3) (4) (5) (6) (7).

Basically the electrolytic method of derusting metals requires that the material or object being cleaned of rust, be completely immersed in, or surrounded by, an electrolyte of sufficient conductivity to carry and distribute the electric current needed for the derusting process. For marine purposes on a large scale, seawater appears to be most convenient and adaptable for use as an electrolyte; however, the electrolyte may well be a solution of any of several salts, acids or bases.

There are two ways in which cleaning can be accomplished, one in which the object being cleaned is made the anode, and the other in which the object being cleaned is made the cathode. Anodic cleaning is rapid and is capable of leaving the metal in a bright smooth condition. When used as the sole method of cleaning objects that are heavily corroded, severe etching or pitting may occur. However, it has been found that

a caustic soda solution (less than 5% by weight), used as an electrolyte will liberate oxygen at a steel anode instead of dissolving the anodic metal itself. In general, except for superficial cleaning and electropolishing, the object to be cleaned is seldom made the anode in the electrolytic derusting process. Most commercial electrocleaning methods use combinations of anodic and cathodic cleaning. The additional baths employed in commercial cleaning processes usually consist of degreasing agents, emulsifiers and wetting agents, rinsing baths and temporary anti-corrosive treatments, after descaling is complete. In order to improve the appearance of an article, when it is cleaned cathodically, cyanides are sometimes added to caustic solutions and the article is given a short reversal of current, (anodic) as the last step in the descaling process.

In cathodic cleaning, the object being cleaned is made the cathode in the electrolytic circuit thereby eliminating the danger of damaging the object through etching and pitting. The principles that apply to cathodic protection also apply to this method; the major differences being that the current density for electrolytic cleaning is generally about 100 times greater or more. Cathodic cleaning is the only electrolytic process that can be safely employed in a sea water electrolyte. Aside from the inherent advantage of electrically protecting the article to be cleaned, the process is free of noise and dust. There is no mechanical or thermal abuse of the metal and lastly the process is economically competitive.

Limitations of the process—Since no single process can be considered a panacea for unlimited application, some of its limitations should be borne in mind. Tightly adherent mill scale is a rather good conductor of electricity and generally non-permeable to the penetration of sea water. As such, electrolytic descaling is not effective in removing mill scale from steel surfaces. Aluminum and lead fittings will generally be attacked due to the alkaline reaction at the cathode (cathodic corrosion) and therefore should be masked or removed from the electrolyte during electrolytic derusting. Further, the cathodic process usually involves the evolution of hydrogen from the cathode. This is a constant source of danger when descaling operations are performed in confined spaces. Lastly, although mild steel does not exhibit tendencies of hydrogen embrittlement when subjected to cathodic cleaning, certain high tensile steele and stainless steels may become embrittled and therefore would require further treatment to restore their ductility.

In the cathodic cleaning process, the electrode functioning as the anode may be one of several materials. Graphite anodes and steel shapes, usually in the form of rods, angles and plates have been used successfully. Scrap metal can be utilized in order to keep costs to a minimum. High silicon iron is being investigated as a possible low cost insoluble anode. The positive terminal of a direct current power supply is connected to the anode through a rheostat of suitable resistance and the negative terminal of the power supply is connected to the object being cleaned.

Theory of electrolytic derusting — When steel is placed in an electrolyte as the cathode and an ample electric current is allowed to flow, a reducing action occurs on the metal surface. Hydrogen ions attracted to the surface of a clean steel cathode are converted to a layer of hydrogen atoms which increase the steel electrode potential in the anodic direction. This phenomenon is known as polarization. The applied voltage needed to drive the required

current during the descaling process causes the potential on the clean portions of the steel cathode to be raised above its hydrogen overvoltage level which results in the liberation of hydrogen gas. Under these conditions substantially no corrosion can occur.

If the steel surface is rusty, this reducing action at the cathode converts some of the ferric oxides or hydroxides to the ferrous form (8) (9) (10). These chemical changes weaken the rust scale and permit its separation from the metal by virtue of its own weight. Any loosely adherent scale that remains can be removed readily by hosing down with water under pressure or by hand scraping. The chemical reactions associated with electrolytic rust removal will vary somewhat depending upon the nature of the electrolyte.

The Cox process—The early work of Cox (12) (13) (14) (15) (16), dealing with electrolytic methods of descaling and electrocoating rusted and badly fouled steel plates led to extensive investigation by the Bureau of Ships, several years later, of the practical application of this process to the descaling of cargo tank compartments of Navy oilers. Since the Navy was primarily interested in restoring rusted steel to its original clean bare condition, and not in coating the steel with calcerous deposits, some modification of the original process resulted. The details of the Cox process were worked out during World War II but conditions at that time did not permit extensive investigation for Naval use. However, the descaling phase of the process was considered sufficiently advantageous from the viewpoint of saving time and manpower, that general instructions were prepared by the Bureau of Ships in 1943 authorizing the removal of rust from cargo tanks of Navy oilers in gasoline service by this electrolytic method. Even so the process was not tried in the Navy until several years after the war.

Toward the end of World War II, the Army Transportation Corps became very active in developing suitable procedures for electrolytic defouling, descaling and electro-coating ship hulls and tanker compartments. Since a great deal of Army Marine transport was on active duty overseas, the work was performed at Transportation Corps Headquarters, 14th Port, United Kingdom Base, Southampton, England (17).

The Army work aroused British interest and as a result, several independent investigations were made by the Admiralty Corrosion Committee covering theoretical and practical consideration of electrolytic descaling. In 1947, the Army authorized Newport News Shipbuilding and Drydock Company to outfit the FS212, a freight and supply vessel, with special equipment to serve as a floating laboratory for the large scale testing of all aspects of the electrolytic process. The results of this extensive project are summarized in a final report (8). Several additional patents were issued to Colonel G. C. Cox at the completion of these studies (18) (19) (20) (21) (22). A more recent account of the electrolytic descaling work which was undertaken by Newport News Shipbuilding and Drydock Company was presented at the annual meeting of the Society of Naval Architects and Marine Engineers in 1953 (23).

Initiation of Test Work—The need for an improved cleaning process for tanker cargo tanks became acute during the latter part of 1947 and early 1948, as a result of the tanker reactivation program. It was therefore decided to conduct an experimental full scale trial

of the electrolytic cleaning method on the cargo tanks of the USS *Cimarron* (AO22) at the San Francisco Naval Shipyard. The results of this trial were sufficiently promising to warrant additional experimentation (10). Early in 1948, Puget Sound Naval Shipyard developed improved electrodes and utilized a system providing much higher current densities than previously used.

In 1948, a project was established at the Material Laboratory of the New York Naval Shipyard for the investigation of the many variables, and principle significant factors involved, in the derusting of steel surfaces by cathodic treatment with and without the formation of the calcerous deposit. The highlights of these studies are described in Section 2 of the paper.

Prior to and concurrent with the laboratory work at the New York Naval Shipyard, Puget Sound Naval Shiyard proceeded with experimental service trials of cleaning Navy oilers by the electrolytic method as these ships became available in the course of normal yard schedules. The results of the work at both Shipyards were reported frequently to each other and to the Bureau. This insured the incorporation of current developments into the program as the work developed. Section 3 of the paper elaborates on the practical methods developed by the Puget Sound Naval Shipyard. Charleston and Pearl Harbor Naval Shipyards also descaled cargo tanker compartments of two Naval oilers by methods similar to those developed at Puget Sound.

SECTION 2—LABORATORY INVESTIGATIONS*

OBJECTIVE—The objective of this investigation was to experimentally explore the field of electrolytic derusting as applicable to flat, plain ferrous surfaces and as part of the final objective to be able to derust or clean any metallic surface regardless of its geometric configuration.

APPARATUS AND MATERIALS:

Specimens—The steel specimens used as the cathode in the majority of the experiments were cut from a large, previously unused sheet of structural steel plate, ⅛ inch thick. This steel plate conformed to Type A, Grade M of Bureau of Ships Specification 4885(INT) of 1 November 1944. It was covered with a rather uniform layer of mill-scale. Specimens were cut to the desired size as follows:

(1) Specimens requiring mill-scale on their surfaces were not subjected to any special treatment.

(2) Specimens requiring uniformly rusted surfaces were first treated for removal of mill-scale by a pickling operation and then rusted over a three-week period. The rusting operation consisted of immersing the specimens for a five-second period twice daily in water containing three percent of sodium chloride. The immersion periods were at time 8 A.M. and 4 P.M. for five consecutive days per week, and during the intervening drying periods the specimens were separated suspended in air at the ambient temperature of 70 degrees F.

*Adapted from New York Naval Shipyard Final Report 5902 "Electrolytic Derusting of Metals" of 14 June 1950.

(3) Specimens requiring painted surfaces were first treated for removal of mill scale, rinsed and washed in fresh water, dried at temperature of 70 degrees F. and then painted as described later.

Steel cathode specimens were used unless otherwise specified and all current densities are computed on the inner surface area facing the anode.

Anode materials were pieces of ¼ inch diameter mild steel welding rod or strips of the ⅛ inch thickness structural plate unless other metals are specifically noted.

Electrolytes: The electrolytes were as follows:

(1) Sodium chloride solutions of various concentrations, prepared by mixing reagent grade sodium chloride and distilled water.

(2) Synthetic seawater, prepared from distilled water and chemicals, in following proportions:

Material	*Grams per liter of water*
sodium chloride	23.00
potassium sulfate	.85
calcium sulfate	1.30
magnesium chloride	3.40
sodium bromide	.050
sodium iodide	.005
silica	.015

(3) Detergents as noted were added to the electrolyte in certain experiments.

Equipment: The containers to hold the electrolyte and anodes were either glass beakers, hard rubbery battery cases or wooden tanks of the required size, as later described.

The direct current power supply for the experiments was obtained from Navy standard portable storage batteries, usually class 6V-SMBD-130AH of Navy Department Specification 17B4h.

Rheostats for regulating current supply were the stepless control carbon pile type, with resistance up to 100 ohms and dissipating capacity of 750 watts per unit.

Electrical instruments of suitable range were used to measure direct currents from 25 milliamperes to 10 amperes and voltages up to 20 volts.

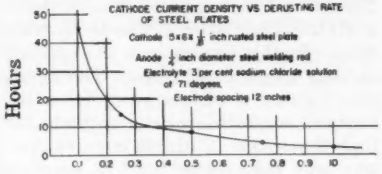
The electrolyte solutions were checked for pH by means of the Beckman pH meter.

Tensile strength specimens were pulled for strength and elongation on a standard tensile strength machine. Specimens for fluxural strength tests were tested on a suitable machine.

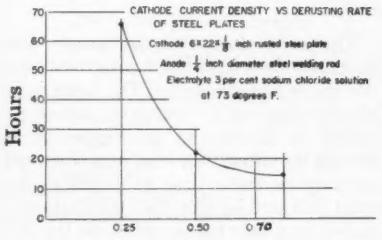
PROCEDURES, RESULTS AND DISCUSSIONS

In the critical phase of these experiments the anode was a single piece of steel welding rod the same length as, and mounted parallel to the vertical centerline of the rusted steel plate which served as the cathode (unless otherwise noted). Except for comparison of results obtained using synthetic seawater, the electrolyte was 3% sodium chloride solution.

Effect of Cathode Current Density on Time and Efficacy of Rust Removal—The experiments were made under identical conditions except that cathode current density ranged from 0.10 to 1.00 amperes per square foot of cathode surface area. Periodic readings were taken on voltage required to maintain the desired cathode current density and the specimens were examined at intervals in order to obtain information on progress of the derusting operation. The experiments were stopped over night, as necessary, and discontinued when the specimens were free of rust.



Amps. per sq. ft.
Figure 1.



Amps. per sq. ft.
Figure 2.

The data plotted in Figure 1 indicate that the rate of electrolytic derusting of steel is nearly directly proportional to cathode current densities over ¼ amperes per square foot, other factors being equal. When the current density is increased to the order of 1.0 ampere per square foot the cathode gases vigorously and is cleaned in what appears to be a proportionally shorter time.

Figure 2 contains the data from another series of experiments in which the cathode was 22 inches in width and the electrode spacing was only 6 inches. Under these conditions derusting is not directly proportional to cathode current density within the same range shown in Figure 1. Apparently the electrode spacing was inadequate to give the anode sufficient throwing power to effectively cover the 22 inch width of the cathode. Electrode throwing power is covered by a later paragraph.

The current required for a large scale derusting operation makes it generally mandatory to use as low a cathode current density as will insure completion of the derusting operation with a reasonable period of time. This consideration would normally limit cathode current density within the range of from 0.25 to 0.50 amperes per square foot of cathode surface area. Cathode current densities appreciably lower than 0.25 ampere per square foot are not advisable when the time element is an important consideration. Cathode current densities higher than 0.50 ampere per square foot normally are not necessary or may not be advisable because of additional factors involved such as gas evolution and possibility of hydrogen embrittlement of the cathode metal.

Effect of Spacing Between Electrodes on Time Required for Derusting—These experiments were run under identical conditions except that spacing between cathode and anode was different in each case, ranging from 3 inches to 21 inches in steps of 3 inches. Voltage data and condition of cathodes were recorded periodically. Operations were discontinued over night, as necessary and stopped upon complete removal of rust from specimens.

ELECTRODE SPACING VS. TIME REQUIRED FOR DERUSTING STEEL PLATES

Inches
Figure 3.

Cathodes 5x6x⅛ inch rusted steel plate.
Anodes ¼ inch diameter steel welding rod.
Electrolyte 3 per cent sodium chloride solution at 70 degrees F.
Cathode current density 0.25 ampere per square foot.

The data illustrated in Figure 3 indicate that electrode spacing, within the limits tested, does not affect derusting time. The variations which do exist in this data are not considered significant.

Effect of Spacing Between Electrodes on Potential Required to Maintain a Given Cathode Current Density—Several experiments were run with electrode spacing progressively changed from 1 foot to 10 feet. Cathode current densities were 0.75 and 3.30 amperes per square foot of cathode surface area. The voltage required for each electrode spacing was measured over a five minute period and the spacing then changed. The data plotted on Figure 4 indicate that the potential required for the derusting process is a function of the electrode spacing and current required.

ELECTRODE SPACING VS. POTENTIAL REQUIRED FOR DERUSTING STEEL PLATES

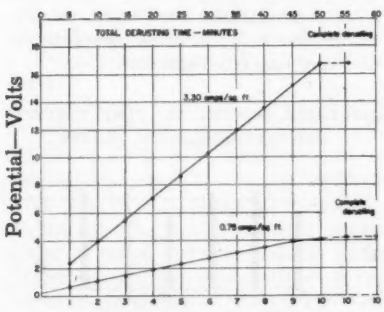


Figure 4.

Cathode 5x6x⅛ inch rusted steel plate.

Anode ¼ inch diameter steel welding rod.

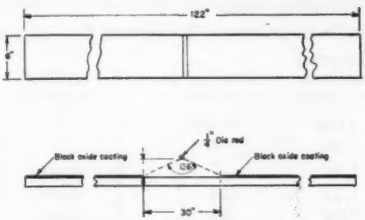
Electrolyte 3 per cent sodium chloride solution at 74 degrees F.

Throwing Power of a Single Anode on a Relatively Large Cathode Surface Area—In this experiment the cathode surface was 6 x 122 inches. The anode was located 6 inches away from the vertical centerline of the cathode 122 inch dimension. Cathode current density was maintained at 0.75 amperes per square foot of inner exposed area. Observations were made on potential required and on amount of cathode surface derusted.

The area closest to the anode was derusted first and then progressively, the more remote areas. The area over which complete derusting was accomplished is illustrated in Figure 5. It should be noted that rust was removed entirely on the center 30 inches of the total 122 inches and was partially reduced to a soft black oxide on the remainder of the plate. Although the derusted area is limited, the throwing power of the anode is sufficiently good to make it only necessary to avoid excessively close electrode spacing in the design of an electrode system, since the area that may be derusted by using a single rod anode can be enlarged by increasing the distance between electrodes.

The correct spacing between the anode and cathode will depend to some extent upon the size and nature of the derusting operation and on the voltage of the available power supply. The voltage required for derusting is increased as the electrode spacing is increased, because of the added resistance in the current path. In order to utilize the throwing power of the anode and to keep the number of anodes to a minimum, the anode should be at least five feet from the closest part of the cathode, provided space permits. The cost of rigging anodes is an appreciable item in a large installation, but it is important that the anodes be located so as to assure a satisfactory distribution

THROWING POWER OF A SINGLE ANODE ON RELATIVELY LARGE CATHODE STEEL PLATE



Derusted after 27 hours

Figure 5.

Cathode 6x122x⅛ inch rusted steel plate.
Anode ¼ inch diameter welding rod opposite center of cathode.
Electrolyte 3 per cent sodium chloride solution at 71 degrees F.
Electrode spacing 6 inches.
Cathode current 3.43 amperes.

of current on the cathode. Anode location is an important factor in derusting a large space, such as a tanker compartment wherein the anode throwing power may be affected by pipes, stiffeners, or other structural members.

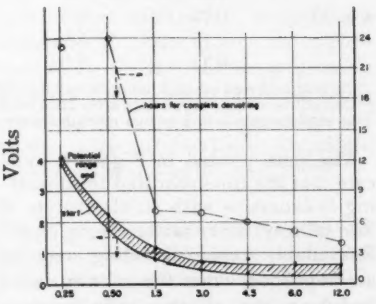
Removal of Mill-Scale by the Electrolytic Method — Several experiments were made to determine the efficacy of this method in the removal of tight mill scale. The specimens were coated with the original mill scale and had only small rusted areas. Various electrode spacing and cathode current densities were used. The observations were made on the applied potential and the condition of the cathodes. The data from these experiments are presented in Table 1. It should be noted that this method, using sodium chloride as the electrolyte, was not effective in removing tight mill scale, even though the ampere hours of current applied was considerably in excess of that normally required to remove rust.

Since thin tenaceous mill scale is composed mainly of ferrous oxide (FeO) chemical reduction by hydrogen to pure metal apparently can not occur at ambient temperatures. Further, the presence of a strong alkaline environment near the steel cathode would tend to maintain the oxide of iron on its surface.

The second phase of this investigation consisted of using cathode specimens which were uniformly rusted prior to the start of the experiments. The anodes and/or the electrolytes were modified as indicated for each case.

Effect on Electrolyte Salinity on Time and Efficacy of Rust Removal—A series of experiments were run under identical conditions except that the salinity of the sodium chloride electrolyte was varied from ¼ to 12 per cent. Observations were made on potentials and conditions of cathodes. The experiments were stopped shortly after derusting had been completed.

ELECTROLYTE SALINITY VS. TIME REQUIRED FOR DERUSTING STEEL PLATES



Salinity, per cent NaCl

Figure 6.

Cathode 5x6x⅛ inch rusted steel plate.
Anode—inch diameter steel welding rod or 1x6x⅛ inch steel strip.
Electrolyte sodium chloride solution at 70 to 74 degrees F.
Electrode spacing 14 inches.
Cathode current density 0.50 ampere per square foot.

TABLE 1

REMOVAL OF MILL SCALE ON STEEL PLATES

Cathodes 5 x 6 x ⅛ and 6 x 22 x ⅛ inch Steel Plates with Mill Scale Anodes ¼ inch Diameter Steel Welding Rods

Electrolyte 3 Percent Sodium Chloride Solution at 71 Degrees F.

Cathode Size	Cathode Current Density	Electrode Spacing	Potential Between Electrodes	Derusting Time	Mill Scale Removal
inches	amps./sq.ft.	inches	volts	hours	%
6 x 22	0.25	5.0	1.04	0	
	0.25	5.0	1.12	7	none
	0.25	5.0	1.01	14	none
	0.25	5.0	0.99	21*	none
	0.25	5.0	1.03	33	none
5 x 6	0.48	2.5	0.63	0	
	0.48	2.5	.69	7	none
	0.48	2.5	.68	22**	none
	0.48	2.5	.69	51	none
	0.96	2.5	.95	51	none
	0.96	2.5	.87	65	none
	1.44	2.5	1.15	65	none
	1.44	2.5	1.09	72	none
5 x 6	0.96	2.5	0.88	0	
	0.96	2.5	.91	7	none
	0.96	2.5	.91	14	none
	0.96	2.5	.93	22	none
6 x 22	0.50	5.0	1.10	0	
	0.50	5.0	1.22	6	none
	0.50	5.0	1.25	12	none
	0.50	5.0	1.27	19	none
6 x 22	0.75	5.0	1.67	0	
	0.75	5.0	1.56	7	none
	0.75	5.0	1.53	13	none

*Current reversed every 2 hours during last 12 hours.
**Current reversed periodically after 22nd hour.
In experiments 3 and 4, two cathodes were used, with only one anode.

The data plotted in Figure 6 indicate that the time required for derusting is excessive with an electrolyte of low salinity, other factors being equal. Reasonably rapid derusting may be accomplished when the salinity is 1.5 to 3.0 per cent. Higher salinities further reduce the time required for derusting but not in proportion to increase in salinity. It should also be noted that when the electrolyte salinity is low the potential required may be excessive. A practical salinity appears to be between 1.5 to 3.0 per cent, however, 1.0 percent may be also suitable depending on the economics of the situation.

Comparison of Derusting with Electrolytes Consisting of 3% Sodium Chloride Solution and Synthetic Sea Water at Different Current Densities—Similar experiments were run with each of the two electrolytes and observations made on the voltage required and the condition of the cathodes. The experiments were discontinued shortly after derusting had been completed on one run, and were continued until fairly heavy residual deposits had accumulated on the cathodes in the other series.

COMPARISON OF 3 PER CENT SODIUM CHLORIDE SOLUTION AND SYNTHETIC SEA WATER IN TIME REQUIRED FOR COMPLETE DERUSTING

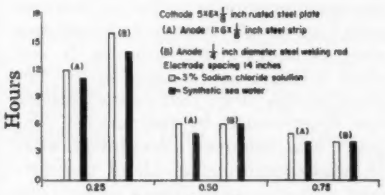


Figure 7.

COMPARISON OF 3 PER CENT SODIUM CHLORIDE SOLUTION AND SYNTHETIC SEA WATER IN POTENTIAL REQUIRED AT THREE CURRENT DENSITIES

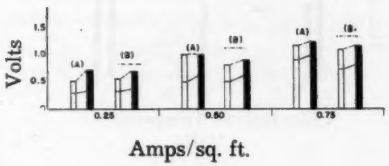


Figure 8.

Cathode 5x6x⅛ inch rusted steel plate.
(A) Anode 1x6x⅛ inch steel strip.
(B) Anode ¼ inch diameter welding rod.
Electrode spacing 14 inches.
□=3% Sodium chloride solution.
■=Synthetic sea water.
—Start of derusting.
- - - Completely derusted.
.-.-. Beyond derusting—total 37 hr.

It was shown that there was little difference between the two electrolytes in the time required for derusting. The residual deposit left on the cathode is different for the two electrolytes, being white for sea water and black for the sodium chloride solution. A spectroscopic analysis of the white residual coating showed principally magnesium with small amounts of iron, calcium, silicon, aluminum, boron, and phosphorous in order of importance. An X-ray analysis of the coating revealed 80 to 90 per cent of magnesium hydroxide. A similar X-ray analysis of the black residual deposit showed Fe_3O_4 (magnetite), only.

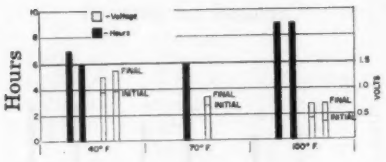
The similarity between derusting times and the potentials recorded are illustrated in Figures 7 and 8, respectively. In Figure 8, lines are used to connect comparison points on the bars.

Effect of Electrolyte Temperature on Time and Efficacy of Rust Removal— In this series of tests observations were made as to voltage required and on the conditions of the rusted cathodes until derusting was complete.

The data indicate that the process is effective in removing rust from steel plates when the temperature of the electrolyte is 40, 70 or 100°F. Within these temperature limits, no saving of time is indicated by the use of 100°F. electrolyte, and it is concluded that electrolyte temperature within these limits is not an important factor in the derusting process. Figure 9 illustrates the differences in derusting time and voltage obtained at the three temperatures. Duplicate runs were made at 40 and 100°F.

Effect of Electrolytic Derusting on Adjacent Painted Surfaces — In this series of experiments the cathodes consisted of 7 x 11 x ⅛" incrusted steel plates, half the area of which was sanded clean and painted. The painting consisted of 1 coat of zinc chromate primer followed 24 hours later by 1 coat of an oleoresinous white paint which also was allowed to dry 24 hours. The anodes were 1 x 6 x ⅛ inch steel strips. The elec-

ELECTROLYTE TEMPERATURE VS. DERUSTING TIME OF STEEL PLATES



Electrolyte Temperature
Volts

Figure 9.

Cathode 5x6x⅛ inch rusted steel plate.
Anode 1x6x⅛ inch steel strip.
Electrolyte 3 per cent sodium chloride solution.
Electrode spacing 14 inches.
Cathode current density 0.50 ampere per square foot.

trode spacing was 6 inches and the electrolyte was a 3% sodium chloride solution at a temperature of 72°F.

The cathodes were derusted using current densities of 0.25, 0.50, 0.75, and 1.00 amps/sq. ft. An auxiliary plate painted as described for the cathodes was suspended in the electrolyte but was not included in the electrical circuit. Observations were made as to derusting time, potential between electrodes and the condition of the paint on both the connected and unconnected plates. Derusting occurred in a manner similar to that of previous tests, removal being accomplished after 14 hours at 0.25 amp/sq. ft. and after 5 hours at 1.0 amp/sq. ft. The paint on the other half of the cathode was deteriorated by the process. The paint was removed completely after 14 hours exposure at all of the current densities tried, there being little or no variation in the rate of removal due to the difference in the current densities. The paint on the auxiliary plate was not affected visably by immersion in salt water during the test. The data for these tests are contained in Table 2.

The third phase of the investigation dealt with additional factors involved in the electrolytic derusting process and with identification and removal of residual coatings deposited on cathodes when the process was continued beyond the time required for removal of rust. These experiments are described in the following paragraphs.

Electrolytic Cleaning of Faying Surfaces—Experiments were run to determine whether faying surfaces could be cleaned. The conditions were as follows:

(1) Electrolyte—3 per cent sodium chloride solution

(2) Anode—steel strip 1 x 6 x ⅛ inches.

(3) Electrode spacing—14 inches.

(4) Electrolyte temperature, 70 degrees F.

(5) Cathode current density, 0.25 to 1.00 amperes per square foot of exposed inner surface area.

(6) Each cathode was composed of one plate 5 x 6 x ⅛ inches with one-half its surface, facing the anode, covered by a 2½ x 6 x ⅛ inch steel plate secured with six ¼ inch diameter steel bolt and nuts. The exposed surfaces of both cathode parts were rusted as previously described for all cathodes. The various faying surfaces were as follows:

TABLE 2
EFFECT OF ELECTROLYTIC DERUSTING ON ADJACENT PAINTED SURFACES
Cathode 7 x 11 x ⅛-inch steel plate half rusted and other half painted
Anode 1 x 6 x 8-⅛-inch steel strip
Electrolyte 3 per cent sodium chloride solution at 72 degrees F.
Electrode spacing 6 inches
Auxiliary painted plate immersed in electrolyte but not electrically connected

Cathode Current Density	Derusting Time	Potential Between Electrodes	Condition of Plates		
			Rusted Cathode	Painted Cathode	Aux. painted plate
amp/sq.ft.	hours	volts			
0.25	0	0.49			
	3	.57	rust loose		
	6	.67	50% clean*	loose at edges	
	10	.67	75% clean*	blistered	
	14	.67	100% clean*	paint off	No effect
0.50	0	0.90			
	2	.97	rust loose		
	6	.96	80% clean*	loose at edges	
	9		100% clean*	blistered	
	14		100% clean*	paint off	No effect
0.75	0	1.25			
	2	1.27	50% clean*		
	6	1.18	100% clean*	loose at edges	
	10	1.19		blistered	
	14	1.19		paint off	No effect
1.00	0	1.54			
	2	1.43	60% clean*	loose at edges	
	5	1.36	100% clean*	blistered	
	10			falling off	
	14			paint off	

*After brushing with wet waste.

(a) Rusted steel against rusted steel.

(b) Clean steel against clean steel.

(c) Painted steel against painted steel.

(4) Rusted steel against painted steel.

(e) Clean steel against painted steel. The clean steel was prepared by cleaning with a wire brush and emery paper. The painted faying surfaces were cleaned and painted as described previously.

(7) The electrolysis was continued until the exposed rusted parts of the cathode were free from rust and in some instances longer. During the process recordings of voltage and cathode condition were made. Promptly upon completion of electrolysis the faying surfaces were disassembled and examined.

The data of Tables 3 and 4 indicate that the electrolytic process is not effective in cleaning faying surfaces, even when continued beyond the point where the exposed cathode surfaces are clean. Further, rusting will likely occur on steel faying surfaces which were clean at the start of the process.

TABLE 3

EFFECT OF ELECTROLYTIC CLEANING ON FAYING SURFACES

Cathode 5 x 6 x ⅛ inch steel plate with 2½ x 6 inch faying surface
Anode 1 x 6 x ⅛ inch steel strip

Electrolyte 3 percent sodium chloride solution at 70 degrees F.
Electrode spacing 14 inches.

Faying Surface	Cathode Current Density	Derusting Time	Potential Between Electrodes	Remarks on Cathode Exposed Area	Faying Area
	amp./sq.ft.	hours	volts		
rust-rust	0.25	0	0.46		
		8	.48	50% clean*	
		16	.60	80% clean*	
		24	.66	100% clean*	still rusted (1)
rust-rust	0.50	0	0.67		
		8	.75	60% clean*	
		16	.87	85% clean*	
		20	.92	100% clean*	still rusted
		24	1.09	100% clean*	(2)
rust-rust	0.75	0	0.99		
		5	1.12	50% clean*	
		8	1.20	80% clean*	
		13	1.27	100% clean*	
		16	1.27	100% clean*	still rusted (3)
rust-rust	1.00	0	1.09		
		4	1.21	50% clean*	
		8	1.31	85% clean*	
		10	1.33	100% clean*	
		16	1.36	100% clean*	still rusted (4)

*After wiping with wet waste.

(1) 50% of rust in original condition, others soft and black.
(2) 60% of rust in original condition, others soft and black.
(3) 90% of rust in original condition, others soft and black.
(4) 95% of rust in original condition, others soft and black.

TABLE 4

EFFECT OF ELECTROLYTIC CLEANING ON FAYING SURFACES

Cathode 5 6 x ⅛ inch steel plate with 2½ x 6 inch faying surface
Anode 1 x 6 x ⅛ inch steel strip

Electrolyte 3 percent sodium chloride solution at 70 degrees F.
Electrode spacing 14 inches

Faying Surface	Cathode Current Density	Derusting Time	Potential Between Electrodes	Remarks on Cathode Exposed Area	Faying Area
	amp./sq.ft.	hours	volts		
Clean steel-paint	0.50	0	0.93		
		7	.93	50% clean*	
		12	.93	90% clean*	
		15	.95	100% clean*	Steel rusty, paint good
rust-paint	0.50	0	0.89		
		7	.83	50% clean*	
		12	.78	90% clean*	
		14	.85	100% clean	unaffected
paint-paint	0.50	0	0.93		
		7	.93	50% clean*	
		12	.89	90% clean*	
		14	.95	100% clean*	unaffected
Clean steel-clean steel	0.50	0	0.80		
		7	.91	50% clean*	
		12	.89	90% clean*	
		14	.93	100% clean*	rusty

*After wiping with wet waste.

Effect of Electrolytic Cleaning on Dissimilar Metals Attached to Rusted Steel Plates—During these experiments various non-ferrous metals were attached to rusted steel cathodes. The following conditions prevailed:

(1) Electrolyte—3% solution of sodium chloride at temperature of 69°F.

(2) Anode—steel strip 1 x 6 x ⅛ inches.

(3) Electrode spacing—14 inches.

(4) Cathode current density—0.50 ampere per square foot of inner surface area.

(5) Cathodes—rusted steel plates 5 x 6 x ⅛ inches, each with a cleaned area 1 x 5 inches to which a clean dissimilar metal strip 1 x 5 x ¼ inches was attached by six ⅛ inch steel bolts with steel nuts. This produced a faying

surface between the steel plate and the dissimilar metal. The dissimilar metals were:

(a) Aluminum, Alcoa 25, 99.1 per cent pure.
(b) Zinc, 99.9 per cent pure.
(c) Lead, 99.9 per cent pure.
(d) Brass, 70 per cent copper and 30 per cent zinc.

(6) During each experiment, a duplicate of the cathode was immersed in the electrolyte but was not connected to either electrode.

(7) The experiments were run until the cathodes had been completely derusted. Then the dissimilar metals were unbolted and all parts thoroughly examined.

TABLE 5

EFFECT ON DISSIMILAR METAL AND FAYING SURFACES

Cathode 5 x 6 x ⅛ inch steel plate, 4 x 5 inch area rusted and 1 x 5 inch area clean and attached to dissimilar metal

Anode 1 x 5 x ⅛ inch steel strip

Electrolyte 3 percent sodium chloride solution at 69 degrees F.

Electrode spacing 14 inches

Cathode current density 0.50 ampere per square foot

Auxiliary strip of dissimilar metal immersed in electrolyte but not electrically connected to electrodes.

Dissimilar Metal	Derusting Time	Potential Between Electrodes	Remarks on Cathode Rusted Plate	Dissimilar Metal	Auxiliary Dissimilar Metal Plate
	hours	volts			
brass	0	0.61			
	7	1.01	50% clean*		
	13	.99	100% clean*	discolored	clean
aluminum	0	0.74			
	7	.91	50% clean*		
	13	.93	100% clean*	corroded, slightly pitted	discolored
zinc	0	0.86			
	7	.97	50% clean*		
	13	.97	100% clean*	white film no pitting	white film
lead	0	0.59			
	7	.85	50% clean*		
	14	.97	100% clean*	slight white film	slight white film

*After wiping with wet waste.
Faying surfaces were not pitted.

TABLE 6

RESIDUAL DEPOSIT ON STEEL PLATE AFTER EXCESSIVE ELECTROLYSIS IN SYNTHETIC SEA WATER ELECTROLYTE AT 69 DEGREES F.

Cathode 5 x 6 x ⅛ inch rusted steel plate
Anode 1 x 6 x ⅛ inch steel strip
Electrode spacing 14 inches

Cathode Current Density	Derusting Time	Potential Between Electrodes	Remarks on Cathode
amp./sq.ft.	hours	volts	
1.00	0	1.25	
	2	1.61	rust loose
	3	1.60	100% clean
	4	1.59	slight white residual coating
	7	1.50	heavier white residual coating
	24	1.56	heavier white residual coating
	32	1.52	heavier white residual coating

Spectrographic analysis of the white residual coating showed principally magnesium, with small amounts of iron, calcium, silicon, aluminum, boron and phosphorus in order of importance. X-ray analysis of the white residual coating showed 80 to 90 percent of magnesium hydroxide.

The data as presented in Table 5 indicate that the brass, zinc, and lead were not appreciably damaged by electrolyte cleaning as determined visually. Pitting occurred on the exposed surface of the aluminum, but not on the faying surface. The fact that attack occurred on aluminum, combined with other data presented later regarding the nature of the residual deposits on the cathodes, suggests that the damage was caused by alkalinity generated at the cathode. Thus, any application of cathodic cleaning methods should carefully consider the nature of the metals to be cleaned as well as that of the electrolyte.

Residual Deposits on Steel Cathodes During Electrolytic Derusting — A series of experiments was run to investigate the formation of residual deposits on steel cathodes during electrolytic derusting. In these experiments, normally rusted steel cathodes were used, the anodes were steel strips, and various cathode current densities and electrolytes were used, the details of which can be found in Tables 6 and 7. The electrolysis period was extended beyond the time required for complete derusting of the cathodes.

The residual deposits left on steel cathodes found during experiments described above were identified by spectrographic, X-ray and/or chemical analysis. Also, the residual material left on steel compartment walls of a vessel undergoing cleaning at New York Naval Shipyard was analyzed. The results are included in Tables 6 and 7. When the electrolyte is synthetic sea water the residual deposits are white, and when the electrolyte is a sodium chloride solution the deposits are black. The white deposit from the synthetic sea water formed at a current density of 1.0 amp/sq. ft. was 80 to 90 per cent magnesium hydroxide with small amounts

TABLE 7

RESIDUAL DEPOSIT ON STEEL PLATE AFTER EXCESSIVE ELECTROLYSIS IN 3 PERCENT SODIUM CHLORIDE SOLUTION AT 71 DEGREES F.

Cathode 5 x 6 x ⅛ inch rusted steel plate
Anode 1 x 6 x ⅛ inch steel strip
Electrode Spacing 14 inches

Cathode Current Density	Derusting Time	Potential Between Electrodes	Remarks on Cathode
amp./sq.ft.	hours	volts	
0.25	0	0.23	
	6	.39	rust becoming loose
	22	.66	slight residual black deposit scraped off for analysis

X-ray diffraction analysis of the black residual deposit showed Fe_3O_4, only.

X-ray diffraction analysis of a black residual deposit taken from the steel walls of tank compartments of the vessel ARD-7 after 168 hours at electrolysis in 1 percent solution chloride solution with platinum anodes at cathode current density of 0.10 ampere per square foot, showed as follows:

65 percent Fe_3O_4
35 percent FeO.OH

TABLE 8

Cathode 5 x 6 x ⅛ inch rusted steel plate
Anode 1 x 6 x ⅛ inch steel strip
Electrolyte synthetic sea water at 73 degrees F.
Electrode spacing 14 inches

Cathode Current Density	Derusting Time	Voltage Between Electrodes	Remarks on Cathode	Remarks on Anode
amp./sq.in.	hours	volts		
1.00	0	1.05		
	4	1.37	100% clean	
	5	1.38	slight white deposit	
	8	1.33	heavier white deposit	
current	24	1.39	heavier white deposit	
reversed	24	1.39		
	32	1.51		unaffected
	96	1.67		unaffected
	120	1.65		unaffected
1.00	0	1.22		
	4	1.52	100% clean	
	5	1.51	slight white deposit	
	8	1.49	heavier white deposit	
current	24	1.43	heavier white deposit	
reversed	24	1.39		
	32	1.67		unaffected
	96	1.83		unaffected
	120	1.77		unaffected

NOTE: The cathodes became anodic when the current was reversed but the white residual deposit was unaffected.

of iron, calcium, silicon, aluminum, boron and phosphorous. The black deposit resulting from the 3% sodium chloride solution at a current density of 0.25 amp/sq. ft. had a composition of 100% Fe_3O_4 (magnetite). The black deposit from the floating drydock using a 1% sodium chloride solution and a current density of 0.10 amp/sq. ft. was composed of 65% Fe_3O_4 and 35 per cent Fo.OH.

Effect of Current Reversal on Residual Deposits Left on Steel Cathodes—The residual deposits were formed on steel plates by using synthetic sea water as the electrolyte and continuing the electrolytic derusting process longer than necessary to remove the rust. The current was then reversed so that the anode became the cathode and vice versa. The results of Table 8 indicate that the long time reversal of the current did not appreciably move the white deposit.

Effect of Addition of Sulfuric Acid to Eletcrolyte Before Starting Derusting Process—In this series of experiments various percentages of sulfuric acid were added to the electrolyte prior to starting the derusting process and experiments ran concurrently. Periodic observations were made on voltage and condition of cathodes the passage of current was continued until the residual coating had been formed or had failed to form during a 48 hour period after rust removal. The electrolyte pH was measured at the start and the end of the period.

Figure 10 illustrates some of the data recorded. It should be noted that the pH of the synthetic sea water became less and less in a fairly constant manner with each addition of H_2SO_4. In Figure 10 this is illustrated by the curve labeled "pH of electrolyte at start of derusting." The corresponding curve for the "pH of electrolyte after derusting" indicates that this pH

EFFECT OF ADDITION OF SULFURIC ACID TO SYNTHETIC SEA WATER ELECTROLYTE ON INITIAL AND FINAL pH AND TIME FOR COMPLETE DERUSTING

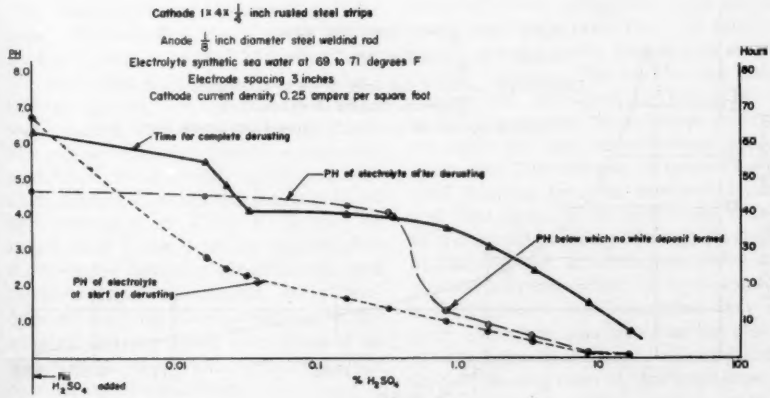

Cathode 1 x 4 x 1/4 inch rusted steel strips
Anode 1/8 inch diameter steel welding rod
Electrolyte synthetic sea water at 69 to 71 degrees F
Electrode spacing 3 inches
Cathode current density 0.25 ampere per square foot
pH
Hours
Time for complete derusting
pH of electrolyte after derusting
pH below which no white deposit formed
pH of electrolyte at start of derusting
0.01
0.1
1.0
10
100
% H2SO4

Figure 10.

remains practically unchanged for additions of acid up to 0.34%. Between this concentration and 0.86% the pH becomes much lower and approaches that of the electrolyte before derusting throughout the remainder of concentrations. None of the white deposit was formed on the cathodes for acid concentrations of 0.86% and greater which corresponds to a pH of approximately 1. It was always formed however at concentrations of 0.34% and less. The other curve "time for complete derusting" indicates that the first additions of acid, even though minor in amount, causes an appreciable drop in the time required for complete derusting. Further additions of acid up to 0.86% causes only a slight decrease in time. Above that concentration the time required again decreases appreciably with each increase in acid content.

It was noted that when sulfuric acid was used in the electrolyte the resulting bare surfaces were left in a highly active condition and were thus subject to rapid rerusting, especially if the acid was not thoroughly removed.

Effect of Adding Sulfuric Acid to the Electrolyte After Formation of Residual White Deposit on Steel— In this series of experiments the acid was added after the steel had been derusted and a heavy white deposit formed. The results are plotted in Figure 11. Apparently slightly less acid is required to remove the residual white deposit if the acid is added after the derusting is complete and the electrolytic process continued than if the acid is added at the start of the cleaning process. The white deposit may be removed by adding a relatively small amount of sulfuric acid but in this case the time required is about 24 hours. When the amount of sulfuric acid added is 0.86 per cent or more by weight, the time required for cleaning the steel of the white deposit is four hours or less. To permit rapid removal of the white deposit, electrolyte pH must be reduced to the order of 1 or lower.

EFFECT OF ADDITIONS OF SULFURIC ACID TO THE ELECTROLYTE AFTER FORMATION OF RESIDUAL DEPOSIT ON THE RATE OF REMOVAL

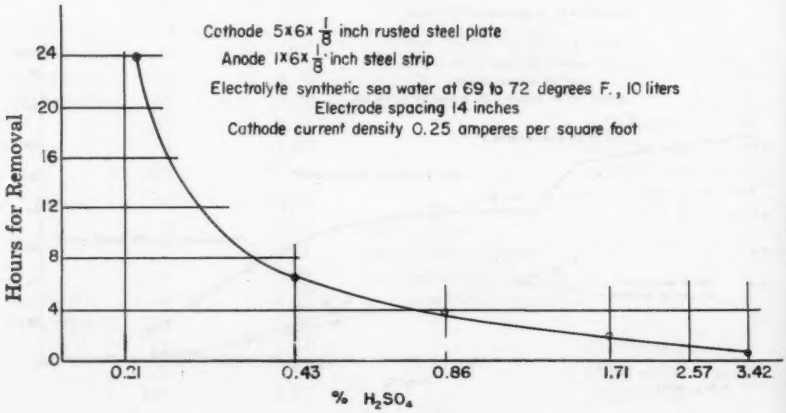


Figure 11.

Table 9.

EFFECT OF ELECTROLYSIS HYDROGEN EMBRITTLEMENT ON STEEL TENSILE

Steel Tensile Strength Specimens 3.25 x 0.357 Inch in Diameter

Specimen Number	Electrolyzed	Yield Point	Breaking Point	Tensile Strength	Elongation in 1.4 inch Gage Length
		Pounds	Pounds	lbs./sq. in.	%
1	No	4600	6500	65,000	36.5
2	"	4800	6700	67,000	36.5
3	"	4600	6700	67,000	37.3
Average 1-3	"	4666	6633	66,330	36.8
4	Yes	4825	6675	66,750	37.1
5	"	4750	6600	66,000	37.1
6	"	4850	6700	67,000	37.1
Average 4-6	Yes	4808	6658	66,580	37.1

Further work on the effect of acid additions on the efficiency of descaling has been accomplished by the U. S. Civil Engineering Research Laboratory, Port Hueneme, California. (24)

Effect of Electrolytic Derusting on Hydrogen Embrittlement of Steel—Two series of tests were run. In the first, the cathodes were tensile strength specimens 3.25 inches in length and 0.357 inch in diameter prepared from medium carbon steel. These clean cathodes were electrolyzed in synthetic sea water at 70° F for 48 hours using a current density of 1.00 amp./sq.ft. of exposed surface area. The anodes were steel strips 1 x 6 x ⅛ inches located 14 inches from the cathodes. At the end of the electrolysis period, the cathode specimens were tested for tensile strength and elongation and the results compared with those from similar specimens unelectrolyzed. The results are tabulated and averaged in Table 9. It will be noted that there was no appreciable differencies between electrolyzed and unelectrolyzed specimens. It is recognized that the data presented in the subject test are open to criticisms as the method used did not adequately test for loss in ductility.

In the second series of tests the cathodes were prepared from two pieces of medium-carbon structural steel, each 12 x 4 x ½ inches. These pieces were butt-welded and then cut into flexural test specimens each 1 x 8 x ½ inches with the welded section at the center of the 8 inch dimension. These clean specimens were electrolyzed in synthetic sea water at 68° F for 72 hours at a current density of 0.50 amps. per sq. ft. of exposed surface area. The anodes were steel strips 6 x 1 x ⅛ inches spaced 14 inches from the cathodes. At the end of the electrolysis period, the electrolyzed specimens and similar specimens unelectrolyzed were subjected to a transverse bend test, with the load applied at the welded part, through an angle of 180 degrees. The results are tabulated and averaged in Table 10. It will be noted that the average flexural strength for the electrolyzed specimens was 7900 pounds as compared to 8542 pounds for the unelectrolyzed, and that none of the specimens failed to withstand bending through an angle of 180 degrees. Inasmuch as the anticipated adverse effect of hydrogen is embrittlement, it is concluded that no such effect was produced on the steels in question. It is now believed that impact testing data or the exposure of the specimen under stresses would have been more conclusive.

Table 10.

EFFECT OF ELECTROLYSIS HYDROGEN EMBRITTLEMENT ON FLEXURAL STRENGTH OF WELDED STEEL SPECIMENS

Specimen Number	Electrolyzed	Maximum Load	Deflection Angle	Specimen Failure
		pounds	degrees	
1	No	8000	180	None
2	"	8300	"	"
3	"	8850	"	"
4	"	8800	"	"
5	"	8000	"	"
6	"	9300	"	"
Average 1 to 6	"	8542	"	"
7	Yes	7800	180	None
8	"	8100	"	"
9	"	8100	"	"
10	"	7600	"	"
11	"	7900	"	"
12	"	7900	"	"
Average 7-12	"	7900	"	"

The fourth phase of this investigation dealt with the effect of the addition of detergents, use of anodes other than steel, and the application of this electrolytic method to the cleaning of a scale coated brass condenser tube.

The Effect of Addition of Detergents on Efficacy of Electrolytic Cleaning—The following proprietary addition agents, in quantities as recommended by the manufacturer, were added to the 3% sodium chloride and synthetic sea water electrolytes at the start of the cleaning process.

a. Antrox A-180, an alkyl aryl polyethylene glycol, an oily viscous liquid.

b. Antarene X-235, the sodium salt of a tetracarbozylic diamine, a white powder.

c. Antaron L-135, the sodium salt of a fatty amide sulphonate, a white powder.

Periodic observations were made on voltage required, condition of cathode, time required for derusting and electrolyte pH reading. These data are recorded in Tables 11 and 12. The three addition agents, as used, were not effective in reducing the time required for derusting or in preventing the formation of residual deposits on the cathode when the cleaning period was extended beyond the time required for complete derusting.

Table 11.

EFFECT OF ADDING ADDITION AGENTS TO ELECTROLYTE BEFORE ELECTROLYZING

Cathode 5 x 6 x ⅛-inch Rusted Steel Plate
Anode 1 x 6 x ⅛-inch Steel Strip
Electrolyte Synthetic Sea Water at 68 Degrees F
Electrode Spacing 14 Inches
Cathode Current Density 0.25 Ampere Per Square Foot

Addition Agent	Derusting Time	Voltage Between Electrodes	Electrolyte pH	Condition of Cathode
	Hours	Volts		
None	0	0.41	6.37	Rusty
	18	.70	5.51	90% free of rust
	19	.71		100% free of rust
	42	.77		Heavy white deposit
	48	.75	5.00	Heavier white deposit
Antarox A-180	0	0.27	6.60	Rusty
0.04% by volume	18	.68	5.62	100% free of rust
	26	.75		Slight white deposit
	42	.78		Heavy white deposit
	48	.78	4.68	Heavier white deposit
Antarene X-235	0	0.37	8.22	Rusty
0.2% by weight	18	.72	7.66	80% free of rust
	22	.71		100% free of rust
	26	.71		Slight white deposit
	42	.75		Heavy white deposit
	48	.75	6.62	Heavier white deposit
Antaron L-135	0	0.30	6.87	Rusty
0.1% by weight	3	.41		Rusty
	19	.81	5.97	100% free of rust
	27	.87		Slight white deposit
	43	.90		Heavy white deposit
	49	.85	5.94	Heavier white deposit

The Effect of the Use of Other Soluble Anodes in Lieu of Steel Anodes— In this series the cathodes were rusted steel, the anodes were strips of steel, magnesium 99.8%, aluminum Alcoa 25, 99.1% and zinc 99.9%. Electro cleaning was continued until the steel cathodes had been derusted, and for an additional period to note the formation of residual deposits. Observations were made on the voltage required and on pH of electrolyte. The data indicate that soluble non-ferrous anodes such as magnesium, aluminum, and zinc may be used in lieu of steel during the derusting process. However, these metals are normally electronegative with respect to steel therefore the applied voltage would normally be high when maintaining the

Table 12.
EFFECT OF ADDING ADDITION AGENTS TF ELECTROLYTE BEFORE ELECTROLYZING
Cathode 5 x 6 x ⅛-inch Rusted Steel Plate
Anode 1 x 6 x ⅛-inch Steel Strip
Electrolyte 3 Per Cent Sodium Chloride Solution at 69 to 71 Degrees F
Electrode Spacing 14 Inches
Cathode Current Density 0.25 Ampere Per Square Foot

Addition Agent	Derusting Time	Voltage Between Electrodes	Electrolyte pH	Condition of Cathode
	Hours	Volts		
None	0	0.23	6.33	Rusty
	6	.39		Rusty
	22	.66	5.97	Free of rust, slight black deposit
Antarox A-180	0	0.15	6.72	Rusty
0.04% by volume	5	.48		Rusty
	21	.62	6.33	60% free of rust
	23	.61		100% " " "
	29	.74		Slight black deposit
	47	.78	5.99	Heavier " "
Antarene X-235	0	0.31	9.35	Rusty
0.2% by weight	5	.45		Rusty
	21	.70	9.84	90% free of rust
	23	.73		100% " " "
	29	.75		Slight black deposit
	47	.79	9.40	Heavier " "
Antaron L-150	0	0.24	6.80	Rusty
0.1% by weight	5	.45		Rusty
	21	.79	6.63	90% free of rust
	22	.79		100% " " "
	29	.80		Slight black deposit
	47	.79	6.63	Heavier " "

anode electropositive with respect to steel during the derusting process. The effect of the use of the various anodes is illustrated in Figure 12. For magnesium, and initially for zinc, it was impossible to attain a current density as low as 0.25 amp/sq.ft. when applying voltages for reversing the polarity of these metals with respect to steel. It should be noted for example, that the time required for complete derusting when using magnesium anodes, was approximately ¼ of that when using steel, but that the amperage for magnesium was 3 to 4 times more than for steel. The comparison between the use of aluminum and steel anodes, however, leads to the conclusion that it may be possible to decrease derusting time by the substitution of aluminum for steel without a proportionate increase in current consumption. Figure 13 illustrates the effect of the use of various soluble anodes on the potential as measured between the electrodes when using synthetic sea water as the electrolyte. Essentially the same type of data was obtained when using 3 per cent sodium chloride.

At zero impressed current the galvanic circuit potential was observed to be the same between steel and the various non-ferrous anodes in either the synthetic sea water electrolyte or the 3% sodium chloride solution. It is also interesting to note that the residual deposits on the cathodes when using synthetic sea water as the electrolyte was recorded as heavy for magnesium and steel anodes, and as slight for aluminum and zinc anodes.

EFFECT OF USE OF VARIOUS ANODES IN DERUSTING OF STEEL ON TIME OF COMPLETE DERUSTING.

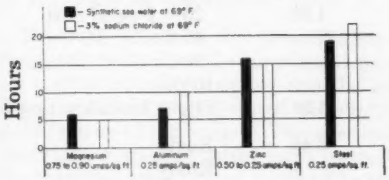


Figure 12.

Cathode 5x6x1/8 inch rusted steel plate.
Anode 1x6x1/4 inch strip of non-ferrous metal, as listed below.
Electrode spacing 14 inches.
■—Synthetic sea water at 69° F.
□—3% sodium chloride at 69° F.

EFFECT OF USE OF VARIOUS ANODES IN DERUSTING OF STEEL ON POTENTIAL BETWEEN ELECTRODES-ELECTROLYTE SYNTHETIC SEA WATER AT 69° F.

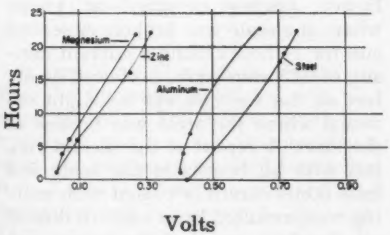


Figure 13.

The Effect of the Use of an Insoluble Anode of Platinum in Lieu of a Steel Anode.—In this series the cathodes were rusted steel plates and the anodes were sections of platinum wire. The experiments were continued until the cathode rust had disappeared and residual deposits had developed.

The condition of cathodes, required voltage and pH of electrolytes are recorded in Table 13. It appears practical to use platinum wire under certain circumstances. The time required for complete derusting was greater than for other anodes tested due to the limited current carrying capacity of the wire used. Present day commercial techniques of cladding wire and metal bars with a thin impervious layer of platinum can reduce the initial high cost of a platinum installation and at the same time increase current carrying capacity of such a system so that it can compete economically with steel anodes. Light weight platinum-clad wires can be suspended conveniently with nylon or other suitable cords resulting in a savings in labor. It is interesting to note that the platinum exhibited no loss in weight during the derusting process and it did not prevent the formation of residual deposits on the cathode after the rust had been removed. A chlorine odor was detected when the platinum anode was used. Recent investigations of high silicon materials show promise as an inexpensive fairly insoluble anode.

The Application of the Electrolytic Cleaning Method to the Cleaning of a Scale Coated Brass Condenser Tube—The tubes for this experiment were removed from the first effect tube nest of the low pressure distilling unit of

TABLE 13

USE OF INSOLUBLE ANODE, PLATINUM, DURING DERUSTING OF STEEL PLATES

Cathode 1¾ x 6 x ⅛-Inch Rusted Steel Plate
Anode Platinum Wire, 0.015 Inch Diameter, 10-Inch Loop
Electrolyte Temperature 68 Degrees F
Electrode Spacing 7-Inches
Cathode Current Density 0.10 Ampere Per Square Foot

Electrolye	Derusting Time	Voltage Between Electrodes	Electrolyte pH	Condition of Cathode
	Hours			
1% NaCl Solution	0	1.96	6.60	Rusty
	2	2.20		Rusty
	18	2.27		Rusty
	26	2.28		Rusty
	42	2.31	4.00	25% free of rust
	50	2.31		40% " " "
	66	2.23		80% " " "
	72	2.25		100% " " "
	74	2.25	3.90	Slight black coating
Synthetic Sea water	0	1.77	6.46	Rusty
	6	2.18		Rusty
	23	2.24	3.82	Rusty
	31	2.22		Rusty
	47	2.33		10% free of rust
	55	2.32		20% " " "
	71	2.31		60% " " "
	78	2.29		70% " " "
	88	2.29		100% " " "
	96	2.29	4.27	Slight white coating

NOTE: Platinum anodes gassed slightly throughout the experiments, but lost no weight. Slight odor of chlorine was noted.

the USS *Tanner*. They consisted of two sections each 2½ feet long and ⅝ inch diameter, heavily coated on the outside with scale. In these experiments the cathode consisted of a 6 inch length of the tube with the lower 4 inches immersed in 3 per cent sodium chloride electrolyte. The anode was a steel welding rod placed 3 inches from the cathode. After 8 hours exposure at a current density of 0.75 amp/sq.ft. the scale was somewhat loosened and could be picked off, except on the side of the tube away from the anode. Heavy gassing occurred at points where the scale was broken. A second run for 14 hours using a current density of 0.25 amp/sq.ft., produced no effect on the scale except for slight removal where the scale was broken at the start. A repeat of the second run, but with all breaks in the scale and bare metal carefully coated with sealing wax, resulted in no current flow at all. Another repeat of the second run but with 1 per cent hydrochloric acid by

weight added to the electrolyte, resulted in the removal of 95 per cent of the scale within 150 minutes with some hard spots remaining. In comparison, a similar specimen of the tube immersed in 1 per cent by weight of hydrochloride acid was completely cleaned of scale in 120 minutes. When using 5 per cent hydrochloric acid the cleaning time for a tube section was 30 minutes. From these results it is concluded that the electrolytic cleaning method will not be effective in removing scale deposits that are similar in nature to the residual coatings deposited from the electrolyte by the electric current itself. The composition of the scale as reported in Table 14 indicates that it is composed mainly of calcium compounds associated with iron, magnesium, and silica.

TABLE 14
ANALYSIS OF SAMPLE OF SCALE REMOVED FROM THE BRASS EVAPORATOR TUBE FROM THE *USS Tanner*

	%
Moisture	1.61
Loss on ignition (chiefly CO_2)	30.73
SiO_2	6.25
Fe_2O_3	10.53
CaO	41.42
MgO	3.61
SO_4	5.34
C	0.05
Ni	trace
Zn	trace

The fifth phase of this investigation conducted at the Puget Sound Naval Shipyard related to the amount of gases given off at the cathode during the electrolyte cleaning process, and the nature of the reaction.* In these experiments unless otherwise stated, the electrolyte was natural sea water. The current density was 0.5 amp/sq. ft. The electrodes were connected in series so that the electricity supplied was the same for each cell in each of the test series conducted, the cathodes were placed inside of an inverted graduated cylinder so that all gas given off was collected and measured. Insulating lacquer or paint was used to cover all bare portions not intended to be used as part of the cathode. The anodes were of sheet aluminum and the cathodes were made in various ways and of various metals as described later under test Series A to E, and H inclusive. The results are illustrated in Figures 14 to 19.

In Series A, the anodes and cathodes were as follows:

Cell No.	Anode	Cathode
2	Aluminum	Platinum
3	Aluminum	Clean steel in contact with a slab of scale
4	Clean steel	Rusty steel
5	Aluminum	Clean steel

It should be noted from Figure 14 that the hydrogen evolution was the same for cells 2 and 5 from which the hydrogen was evolved in theoretical amounts, and progressively lower for cells 3 and 4. Plate 1 shows the assembly of cell 3 of series A. The rust on the cathode of cell 4 was dark and red at first. This color changed to black with the rust sloughing toward the end of the run. The iron content of the electrolytes of this series were determined after the electrolysis and was as follows:

Cell 2—0.1 ppm
Cell 3—1.5 ppm
Cell 5—0.4 ppm
Blank—0.1 ppm

The electrolyte for cell 4 was not analyzed because an iron anode had been used and considerable iron introduced from this source. These data show that very little iron is dissolved from the cathode.

*These tanks were descaled in pairs; for larger tanks (such as AO class) requiring larger anodes and individual descaling, time and material would be approximately doubled.

VOLUME OF HYDROGEN EVOLVED

Series "A"

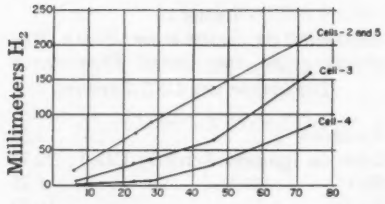
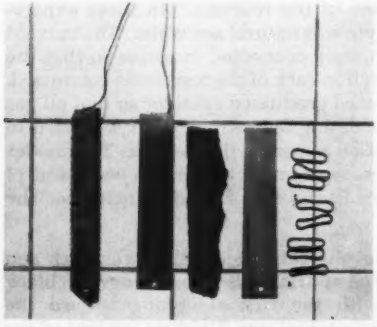


Figure 14.

ASSEMBLY AND PARTS OF CATHODE OF CELL NO. 3, SERIES A



Courtesy of Bureau of Ships

PLATE 1

(a) Assembled Cathode
(b) Clean Steel Plate
(c) Piece of Rust
(d) Porous Wood for Mechanical Protection
(e) Rubber Bands

In series B, the cathodes were as follows:

Cell 1—Platinum
Cell 2—Clean steel
Cell 3—Clean steel surrounded by ferric hydroxide held mechanically around the cathode by a cloth sack
Cell 4—Clean copper
Cell 5—Clean copper and ferric hydroxide as for Cell 3

The amount of hydrogen evolved is shown in Figure 15. The volume of hydrogen produced was the same for all of the cells throughout the electrolysis. These data indicate that the ferric hydroxide did not react and that the copper cathode behaved in a similar manner as a steel cathode.

VOLUME OF HYDROGEN EVOLVED

Series "B"

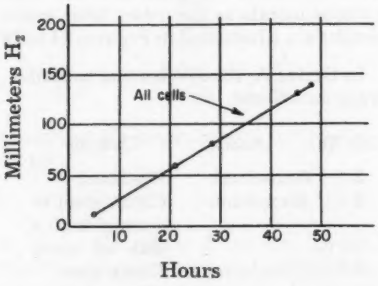


Figure 15.

In series C, the cathodes were as follows:

Cell 1—Platinum

Cell 2—Clean Steel

Cell 3—Clean steel surrounded by ferrous hydroxide held mechanically around the cathode by a cloth sack.

Cell 4—Clean steel surrounded by powdered scale held as described for Cell 3.

Cell 5—Clean copper cathode surrounded by powdered scale held as described for Cell 3.

The amount of hydrogen evolved is shown in Figure 16. It should be noted that the volume of hydrogen produced was the same for Cells 1, 2, and 3. Cells 4 and 5 evolved a somewhat lower amount of hydrogen thus indicating that another reaction was occurring. After the test run was complete the apparatus was allowed to stand for 24 hours to determine if there was any mechanically held gas in cathodes 3, 4, and 5 that would come out. None was found. The scale used was magnetic but the ferrous hydroxide was not.

VOLUME OF HYDROGEN EVOLVED

Series "C"

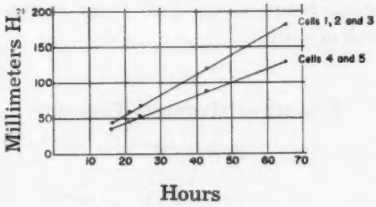


Figure 16.

In series D, the cathodes were as follows:

Cell 1—Platinum

Cell 2—Clean steel in contact with a slab of scale, with the surface of the scale normally away from the metal away from the cathode.

Cell 3—Similar to Cell 2 except that the slab scale was reversed so that the surface normally in contact with the metal was away from the cathode.

Cell 4—Similar to Cell 2 except that of steel.
clean copper was used instead

Cell 5—Similar to Cells 2 and 4 except that Bendalloy (an easily fusible alloy of tin, bismuth, cadmium, and lead) was cast onto the scale. The surface of the scale next to the Bendalloy was the side normally next to the metal.

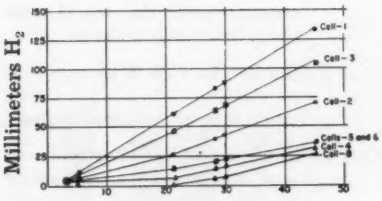
Cell 6—Similar to Cell 5 except that the surface of the scale normally in contact with metal was turned away from the cathode as in Cell 3).

Cell 8—Rusty Steel

The amount of hydrogen evolved from each is illustrated in Figure 17. It was noted that scale and rust in contact with the metal reduced the amount of hydrogen evolved and the closer the contact between the scale or rust to the metal the less hydrogen produced. The differences between Cell 1 and the remaining cells appear to be due to difference in closeness of contact between the metal and the scale or rust. Cell 7 of this series had a Bendalloy cathode, but difficulty was experienced which made the results unreliable.

VOLUME OF HYDROGEN EVOLVED

Series "D"



Hours

Figure 17.

Series E repeated Series D for this Bendalloy cathode. In Series E the cathodes were as follows:

Cell 1—Platinum

Cell 2—Cast Bendalloy cast onto scale with the surface of the scale normally in contact with the metal turned toward the Bendalloy.

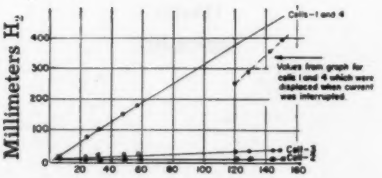
Cell 3—Similar to Cell 2 except that the surface of the scale normally in contact with the metal was turned away from the Bendalloy.

Cell 4—Bendalloy

Due to the electric circuit being interrupted during part of the run, the time interval versus hydrogen volume relationship is not the same as for Series D. However, time is the same for all of the cells. Figure 18 illustrates the results obtained. The upper portion of the graph for Cells 1 and 4 is an extrapolation of the lower portion since the upper portion was displaced due to the current interruption. This extrapolation is based on the fact that this graph represents the theoretical amount of hydrogen that is possible to be evolved. The curves for Cells 2 and 3 lead to the conclusion that the reaction which does not produce hydrogen is more complete when the side of the scale normally in contact with the metal is next to the cathode. This difference could be due to differences in the degree of contact between the two faces of the slab of scale and the cast Bendalloy as previously suggested or it could be due to composition differences between the two faces of the slab of scale.

VOLUME OF HYDROGEN EVOLVED

Series "E"



Hours

Figure 18.

In Series H the anodes and cathodes were as follows:

Cell No.	Anode	Cathode
1	Aluminum	Platinum
2	Aluminum	Same as Cell 2 of Series D
3	Aluminum	Rusty steel
4	Aluminum	Steel coated with mill scale
5	Aluminum	Clean steel
6	Steel	Rusty steel
7	Steel	Clean steel

The results are illustrated in Figure 19. It will be noted that the hydrogen evolved was essentially the same in volume from Cells 1, 4, 5 and 7. Also steel substituted for aluminum in the anode made practically no difference in the volume of hydrogen evolved. The results obtained with Cell 4 for which the cathode was steel coated with mill scale were consistent with results reported in the preceding paragraph in which electrolytic cleaning failed to remove a mill scale coating. No removal would be expected since apparently no reaction other than evolution of hydrogen is taking place as it appears to be for Cells 2, 3 and 6. Plates 2 and 3 show apparatus used in Series H.

VOLUME OF HYDROGEN EVOLVED
Series "H"

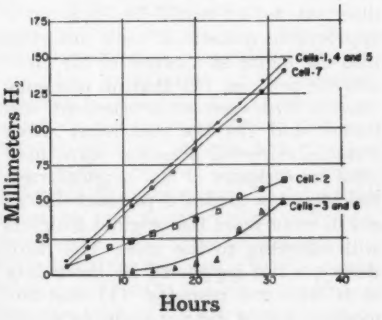
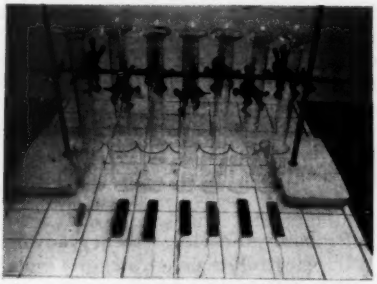


Figure 19.



Courtesy of Bureau of Ships

PLATE 2

GENERAL VIEW OF CELLS AND CONTROLS, SERIES H.

Courtesy of Bureau of Ships

PLATE 3

CATHODES AND GAS COLLECTORS OF SERIES H.

Discussion of Derusting Theory — Careful observations of numerous electrolytic experiments using 3% sodium chloride as an electrolyte revealed that the first outward indication of cleaning is that of the lifting of an outer layer of red rust presumably by the action of the hydrogen. The higher the current density, the faster is the removal of the red rust layer. The loosened red rust is observed to fall off in flakes which do not appear to have been acted upon chemically. A black residual layer remains after this red rust has been removed. It is not easily detached by

further gasing. Instead the cathodic reaction seems to have a gradual softening effect which makes the later removal of this black coating comparatively easy by brushing or wiping. It was also observed that a few drops of phenolpthalein indicator turn pink in the vicinity of the cathode showing the presence of $(OH)^-$ ions.

While the purpose of this investigation was not to determine the theory of cathodic derusting, it is considered pertinent to present several of the theories that have been advanced and to comment briefly on the purport of this data. These theories are:

1. Probably the oldest theory advanced to explain cathodic derusting is that the electrolyte penetrates the scale and rust and then under the influence of the electric current dissociates at the metal rust interface with the liberation of hydrogen which blasts off the scale.

2. Another theory, and one recently advocated by Zapffe (11) is that the hydrogen formed enters the metal lattice at the exposed areas. These atoms then unite to form molecules within the slender metal sub-crystalline openings which apparently exist as a vast pattern throughout every metal. These occlusions of compressed hydrogen diffuse along the planes of crystalline symmetry, the gas pockets breaking from one domain to another. The movement of these gaseous occlusions to the surfaces underlying the scale adjacent to the absorption areas blasts off the rust.

3. According to another theory, water at the rust-metal interface is dissociated into $(H)^+$ and $(OH)^-$ ions by the electric current. The ions are liberated in molecular form as a gas at the insterstices of the rust layer and the excess $(OH)^-$ ions which remain react with the bare steel to form ferrous hydroxide. The compound, slightly soluble and slimy in character gradually lodges at the rust interface and thus loosens the bond between the metal and the rust, allowing the rust to drop off or be vigorously scrubbed off by the hydrogen gassing.

It is believed that the first theory can be eliminated from consideration on the basis that under it hydrogen would be evolved immediately on a rusted plate, which is not the case. Also any rust or scale film sufficiently gas tight to permit a hydrogen build up great enough to blast off the tightly adhering rust or scale would likely be sufficiently water tight to prevent the migration of the electrolyte through the rust to the metal interface in the first place. The second theory is not supported by these data in at least three respects: (1), that no hydrogen is released from the metal cathode when the electric current is discontinued as would be expected if appreciable quantities were absorbed into the metal as a result of the electrolytic process; (2) that no tendency toward hydrogen embrittlement was found; and (3) the rust layer when initially removed does not leave bare steel or residues of the original rust, but leaves a modified product different in color from the original which is still adhering to the steel. The third theory is not supported by these data in at least two respects: (1) that immediate gasing did not occur as would be anticipated if ferrous hydroxide

was being formed; and (2) in the initial rust removal the entire layer of rust was not removed and a residual slimy layer left behind as would be anticipated, but instead an outer layer of rust sluffed off leaving behind a layer of a tightly adherent and relatively hard product, which gradually softened and became removable as the electrolytic process continued. Based on the results at hand, the most likely theory is that the electrolytic action at metal-rust interface of the cathode results in a reduction of the rust to a lower valence oxide of hydrated oxide, as illustrated by the following reactions:

$$3Fe_2O_3 + 2H \rightarrow 2Fe_3O_4 + H_2O$$
$$4Fe_2O_3 + 2H \rightarrow 2FeO.OH + 2Fe_3O_4$$

SECTION III

The final phase of the electrolytic descaling process which ultimately determined its feasibility and practicability was the full scale cleaning operations undertaken by Puget Sound, San Francisco and other naval shipyards.

USS Solomone (AO 26)

In 1942, without the advantage of the experience gained from the extensive investigations that followed, an attempt was made to descale and electrocoat two gasoline-carrying tank compartments of the *USS Solomone (AO 26)* at the Norfolk Naval Shipyard. Although general descaling was accomplished, ineffective anode design prevented the even deposition of the calcareous deposits on the tank surfaces.

USS Cimarron (AO 22)

During 1947 and 1948, electrolytic descaling was given new impetus because of the acute shortage of aviation gasoline carrying tankers. The Navy oiler reactivation program caused an intensive exploration of economical methods for cleaning these oilers, most of which had several tanks in gasoline service, without contaminating aviation gasoline cargos. The *USS Cimarron (AO 22)* was selected as the first vessel to participate in a full scale experimental installation of the electrolytic descaling methods. (10) The tests were conducted in the No. 2 centerline gasoline tank and No. 8 port and starboard cargo oil tanks. The conclusions of the test indicated that the descaling method could be practical and economical. The results showed that current values in the range of ¼ ampere per square foot applied from anodes six feet from the cathode tank surface would produce general descaling in 48 hours. The experiment pointed out that completeness of work is dependent on the design and placement of the anodes, the current density and duration of application of the current. Chlorine and hydrogen generation were a minimum since soluble steel anodes and reasonable current densities were used. In general, the experiments confirmed the fact that under normal conditions, safety precautions with respect to hydrogen, such as venting of the tanks, no smoking, welding, or burning in the immediate vicinity of the work, were adequate. The report indicated that this method could be used with light sandblasting or wire brushing to prepare a tank for painting. Also no damage to the ship structure resulted from this procedure. Plate 4 shows location of typical anodes inside a wing tank. Plate 5 illustrates the uneven distribution of current with its consequent spotty descaling in the corner of the No. 2 cargo tank of the *USS Solomone*. This effect was consequently corrected at Puget Sound with an improved anode design. Apparently for proper descaling of tank corners, anode to cathode distances should not exceed the recommended 6 foot spacing, and anodes should be extended into corners and recesses where necessary.

Courtesy of Bureau of Ships

PLATE 4

TYPICAL ANODE LOCATION IN A WING TANK.

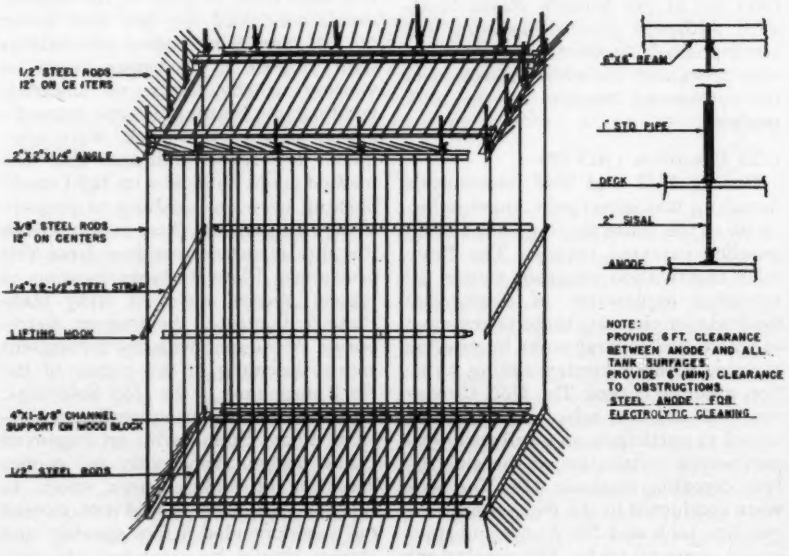


Figure 20.

Courtesy of Bureau of Ships

PLATE 5
VIEW OF CORNER OF CENTER LINE TANK SHOWING UNEVEN CURRENT DISTRIBUTION

Courtesy of Bureau of Ships

PLATE 6
VIEW OF MOTOR GENERATOR ASSEMBLY FROW VESSEL.

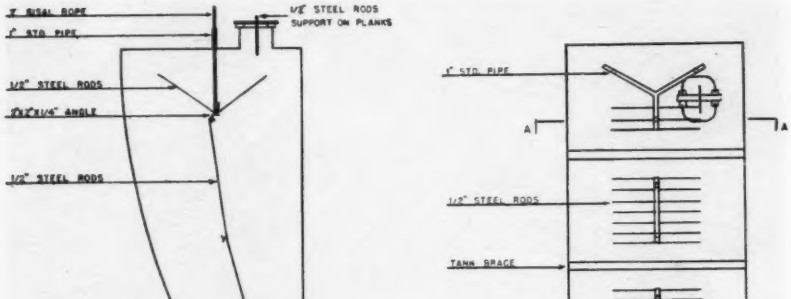


Figure 21.

USS Kennebec (AO 36)

The initial experiments at San Francisco on the *USS Cimarron (AO 22)* with its attendant success motivated the Puget Sound Naval Shipyard to establish a project for adopting electrolytic descaling procedures to production methods. The Bureau of Ships assisted by supplying supporting funds. Improved anode design and fabrication, use of higher current densities, and the effect of additives in the electrolyte were some of the phases of study undertaken.

The first series of full scale experiments were undertaken on the *USS Kennebec (AO 36)* (25). Five petroleum cargo tanks were descaled using anodes closely conforming to the tank wall surfaces by means of a curtain type anode design. Generator capacity was provided to supply a relatively high current with resultant high current densities. Several factors bearing on the completeness and efficiency of descaling were investigated; namely, the effect of current reversals; the effect of acid additions to the electrolyte; effectiveness of an alkaline chromate wash in protecting the tank wall surfaces; comparison of hot fresh water washing and cold sea water washing; and means of rapid flushing and sludge removal.

After drydocking the vessel, a 10-inch valve was installed at a position on the apparent low surface of the tank to facilitate emptying and desludging operations. The centerline tanks were rigged with an anode array consisting of ½-inch steel bars spaced on 12-inch centers as shown in Fig. 20. The wing tanks were fitted with a different anode arrangement which is illustrated in Fig. 21. The tanks were found to be descaled within a period of 36 hours and after hosing down, they were considered satisfactory for carrying aviation gasoline. Power was supplied through seven 1500 ampere DC welding generators with a resultant current density of approximately 0.4 ampere per square foot at a driving potential of 12 volts. (See Plate 6).

RESULTS OF THE EXPERIMENT

Final tank surface conditions— Upon descaling of centerline tank No. 1 to bright metal, the tank walls rapidly corroded while draining down, even though an alkaline chromate wash was used. This condition was due to the treatment with acid and the current reversal which left the metal free of oxide. Because of this, it was decided to omit the use of acid and current reversals on subsequent tanks, thus permitting the calcareous deposits to remain on the cathodic tank walls. Rapid corrosion after descaling was not apparent in the remaining tanks, and therefore the use of the chromate wash was discontinued. Current reversals alone were not successful in removing these calcareous deposits.

Optimum current density — An increase in current density was found to be effective in reducing the time and cleaning ability of the electrolytic descaling process. This was apparent in the centerline tank No. 8 where the bottom, usually the most difficult section to treat, was fully descaled when the anode current density was doubled. Although higher current densities are beneficial for removal of scale the decisive factor can generally be attributed to effective current distribution by means of careful anode design, location and arrangement.

Anode Area—It was concluded that the area of the anodes was insufficient in relation to the tank surfaces (framing included) due to the heavy attack on the anodes in the No. 8 port and starboard tanks. An increase of area could be achieved by using a two-curtain anode in similar tanks.

Current distribution—In order to preclude possible voltage drops in the anode rig, functions which would effect even current distribution, special jumper leads were installed on the anodes of centerline tanks 1 and 2. A voltage drop survey made on one anode revealed negligible voltage variation and therefore the other tanks were wired without jumpers. The electrical connections were made to one edge of each anode rig which greatly facilitated the wiring hook-up.

Washing down operations — Best results were obtained in washing down operations when salt water fire mains with 2 inch fire hose and fire nozzles were utilized. High pressure fresh water from Wheeler units with special nozzles having ⅜-inch jet opening also gave good results. Hot water had the advantage of heating the side walls and drying out the tanks rapidly but was not considered necessary.

Intermittent flushing—As a result of partial draining of tanks during inspections, a flushing and renewal of sea water occurred. The effect resulting from this procedure was not readily determined during this experiment.

Hydrogen Evolution — Although hydrogen is evolved in the electrolytic descaling of fuel tanks, the possibility of trapping large volumes of the gas was eliminated by keeping the tanks pressed full of water and allowing the hydrogen to escape to the open deck through standpipes provided for the anode supports. Hydrogen gas diffuses rapidly in the air and tests indicated that the atmosphere one foot above the manhole was non-explosive. As a precautionary measure, no smoking or welding was permitted in the near vicinity of the tank being descaled.

Cost comparison—As compared with sandblasting of tanks, the initial electrolytic descaling of five tanks together with the additional time required for experimental work was less expensive and was accomplished in a shorter period. Principal savings over sandblasting are due to the reduction in manual labor and elimination of staging. On the basis of results obtained in experimental descaling of five tanks on the *USS Kennebec (AO 36)*, the following conclusions were made:

(1) The process is effective in descaling of cargo tanks for use in carrying aviation gasoline and is readily adaptable to production work on ships in drydock or alongside piers.

(2) The operation is relatively economical and does not require the construction of staging as in sandblasting.

(3) Increase in effectiveness was obtained by higher current densities and anodes conforming to the contours of the tank walls at approximately six feet clearance, provide uniformity of descaling.

(4) Conversion of motor generators to provide separate field excitation eliminates need for individual resistance grid units.

Plates 7 through 10 inclusive show the effectiveness of descaling in the tanks.

Courtesy of Bureau of Ships

PLATE 7

DECK BEAM AFTER 24 HOURS OF ELECTROLYSIS: NOTE SCALE PEELING FROM STIFFNERS.

Courtesy of Bureau of Ships

PLATE 8

TANK AFTER ELECTROLYTIC DESCALING. DARK AREAS ARE WHERE DEPOSIT HAS BEEN REMOVED DURING HOSING DOWN.

Courtesy of Bureau of Ships

PLATE 9

VERTICAL KEEL AFTER 28 HOURS ELECTROLYSIS PRIOR TO HOSING DOWN.

Courtesy of Bureau of Ships

PLATE 10

VERTICAL KEEL (SAME AS PLATE 9) AFTER HOSING DOWN.

Courtesy of Bureau of Ships

PLATE 11

VIEW INTO TANK IMMEDIATELY AFTER DESCALING AND DRAINING DOWN, SHOWING UPPER GRID OF ANODE AND SHEETS OF RUST WHICH HAVE FALLEN ON ANODE FROM OVERHEAD.

Courtesy of Bureau of Ships

PLATE 12

VIEW INTO TANK AFTER ELECTROLYTIC DESCALING AND DRAINING DOWN, SHOWING UPPER CORNER OF ANODE AND LOOSE SHEETS OF RUST ON BULKHEAD.

USS Kishwaukee (AOG 9)

Shortly after the successful descaling operations were carried out on the *USS Kennebec (AO 36)*, another tanker, *USS Kishwaukee (AOG 9)* was selected for descaling 10 of its cargo tanks (26). The descaling method employed on this ship was similar to that on the *USS Kennebec*, except that current densities were higher and duration of descaling time was shorter. In general current densities of 0.5 to 0.7 ampere per square foot of tank surface will descale completely in 18 to 24 hours respectively. The use of a prefabricated anode design, permitting easy assembly and disassembly resulted in the savings of time and anode materials. Plates 11 and 12 show large sheets of rust descaled off tank surfaces.

A cost estimate for descaling the ten cargo tanks of the *USS Kishwaukee (AOG 9)* was given as follows:

DESCALING COSTS

	Started	Completed	Working Days
Descaling Time	7/29	8/7	7
Total Time (all Work)	7/26	8/10	12
Total man days			281.4
Labor Cost* $12.50 per day			$3,517.50
Material			560.00
Power			150.00
Total for 10 tanks			4,228.00
Average Cost Per Tank*			423.00

*These tanks were descaled in pairs; for larger tanks (such as AO class) requiring larger anodes and individual descaling, time and material would be approximately doubled.

These costs may be translated into expected costs under present economic conditions.

Labor and overhead @ $40 per man day =	$11,256	
Material @ 2 times former cost	1,120	
Power @ 2 times former cost	300	
Total for 10 tanks	$12,676	
Average cost per tank		$1,267.60

Other Vessels:

Further testing and modification of the electrolytic descaling process continued with experiments on the *USS Namakagon (AOG 53), USS Nantahala (AO 60), USS Severn (AO 61)* and *USS Taluga (AO 62)* (27). Changes in anode spacing and design and the inclusion of an intermediate wash down and clean out during descaling operations resulted in a more satisfactory descaling process, especially for bottom areas. This work resulted in the following recommended procedures for modifying the electrolytic descaling process:

(1) Provide an intermediate drain-down operation after a minimum of 16 hours descaling followed by further descaling for 16 to 24 hours.

(2) Thorough degreasing prior to electrolytic descaling is important.

(3) Increase anode rod spacing from 12-inches to 18-inches and diameter from ½-inch to 9/16-inch. Insulate bottom grids from remainder of anode and feed by 2 motor-generators to give 2400 amps.

(4) Increase cathode to anode distance from 4 feet to 6 feet, except bottom anode which is 5 feet.

(5) Provide hand operated winches for raising and lowering of anode grids. Increase size of standpipes to 1½ inch pipe size to reduce splashing of water onto the deck during the escape of gases through standpipes.

The sum total of the work at the Puget Sound Naval Shipyard culminated in a final report on the detailed procedure to be followed for electrolytically descaling cargo tanks. (28)

PRACTICAL DETAILS OF ELECTROLYTIC DESCALING

In order to obtain consistant results, it is necessary to defuel cargo tanks and remove oil and sludge prior to performing descaling operations. A vapor injection method was developed for the purpose of rendering the tanks safe for the entry of personnel which is also suitable for removing troublesome oil residues. In this method, fuel oil deposit on the tank walls is heated

by steam to reduce its viscosity. Diesel oil is then injected with steam to remove as much oil as possible through a solvent action after which the separate components of a soap are added. The fatty acid component is soluble in the fuel oil diesel oil layer and when saponification takes place through the addition of an alkali, the oil and steam condensate is emulsified.

In brief the vapor injection consists of the following sequence of operations:

1. Ventilating when necessary.
2. Defueling.
3. Stripping.
4. Steaming.
5. Injection of cleaner.
6. Ventilating.
7. Washing.

Following the removal of oil and sludge, the ship is then readied for electrlytic descaling.

SECTION IV—SUMMARY AND CONCLUSIONS:

Laboratory studies indicated that time for derusting varies with the salinity of the electrolyte and the current density on the cathode. It is largely independent of temperatures within 40 to 100° F. No significant differences in derusting times could be observed between synthetic sea water and a 3% NaCl solution. Cathodic cleaning readily removed oleoresinous adherent paint from a sandblasted steel surface but was generally ineffective in removing rust between faying surfaces and also deteriorated aluminum cathodes. Residual deposits left on steel are mainly composed of magnesium hydroxide (white) when a sea water electrolyte is used. A black residual deposit of iron (Fe_3O_4 or Fe_3O_4 + FeO.OH) results from a NaCl electrolyte. Prevention of white deposits on tank surfaces during electrolysis or its rapid removal after electrolysis can be accomplished by the addition of 0.86% H_2So_4 by weight to the electrolyte. White deposits cannot exist in acid solutions of pH 1 or lower. Hydrogen embrittlement does not occur on mild steel plate subjected to electrolytic descaling in sea water. Several commercial addition agents added to the electrolyte were ineffective in reducing the time for derusting. Soluble metal anodes other than steel can be used, but higher driving voltages are required to maintain the normally electronegative metals electropositive during electrolysis. Nonferrous anodes do not prevent formation of residual deposits when electrolysis is extended beyond time required for rust removal. Insoluble anodes such as platinum act in the same manner as non-ferrous metals in regard to formation of residual deposits, and in addition may extend time of derusting because of economic limitations of anode area, as well as generate chlorine gas at the anode. Electrolytic descaling is ineffective in removing scale of the type found on brass evaporator tubes. Further, hydrogen liberated at the cathode enters into the chemical reduction of ferric oxide (Fe_2O_3) and is liberated in stoichometric quantities after chemical reduction is complete.

Electrolytic descaling is a rapid and possibly less expensive method than manual and mechanical methods for removal of heavy scale in large tanks. It has the additional advantage that no metal is removed from the tank surfaces, and the descaled metal is left in a passive condition less subject to rapid rust formation. The process is applicable to large floodable voids,

large structures which can be immersed in sea water, and small parts which can be immersed in tanks containing the electrolyte. It has particular application in removing rust from cargo tanks, being cleaned for converting to light fuels such as aviation gasoline where contamination must be avoided. Removal of oil and sludge is a prerequisite prior to descaling operations. Essentially demountable grid anodes arranged in curtains roughly conforming to the geometry of the tank are energized by low voltage high current sources such as DC welding generators. The tank acts as the negative ground for the electrical circuit. The sea water electrolyte which fills the tank completes the circuit. The electrolysis reactions which take place during descaling electro-chemically reduces the iron oxides at the metal interface and causes the scale to slough in sheets. When operating at current densities of ½ to ¾ amps per square foot, descaling can be carried out in about 30 to 40 hours. Draining and flushing the tanks complete the operation.

Recommendations: It is recommended that:

(1) The electrolytic descaling process be exploited by the marine industry.

(2) An anode system be designed for a drydock which would electrolytically descale and remove old paint from a hull at time of overhaul. (The ship could be ballasted so that paint removal in way of the boot top could be accomplished.)

(3) A review of surface standard requirements for precision machinery and small objects be made to determine the feasibility of reclaiming corroded equipment.

(4) A method be standardized for the non-destructive cleaning of rusted panels for laboratory and field corrosion studies.

(5) Research and development go forward along the following lines in order to provide wider versatility and application in many naval and industrial fields:

   a. Determine best methods of forming and stabilizing uniform adherent electrocoatings deposited from sea water in tanks and on other structures for the purposes of achieving greater corrosion resistance in service. (The British have experimented with chromate and silicate solutions for hardening purposes but have met with little success.)

   b. Develop techniques for painting over coatings of controlled character.

   c. Investigate addition of additives to the electrolyte which may produce a descaled bare steel surface suitable for painting.

   d. Investigate development of movable light-weight staging, mechanically operated on rails for coating application in tanks, which would materially reduce labor costs in applying coating after the electrolytic process.

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The entire program at the Bureau of Ships was under the Administrative Direction of Commander H. H. Fox, Jr., USN.

The recommendations and opinions expressed in this article are those of the authors and not necessarily those of the Navy Department.

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STRESSES FOR PRESSURE VESSELS AND BOILERS UP TO 650° F

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1. INTRODUCTION

The differences of opinion regarding allowable stresses and weld efficiencies for boilers and pressure vessels are very great. In the United States the allowable stress is one-quarter of the ultimate tensile strength, combined with a weld efficiency of 95, 90 and 80%, respectively, dependent on whether radiographic examination and/or stress relieving is to be carried out or not. In Great Britain the same stress is permitted, while the weld factor depends on a special classification. The first-class vessel, stress relieved and radiographed, has a maximum weld efficiency of 95%, the third-class vessel, nonradiographed and nonstress relieved, with very limited inspection, has a weld efficiency of about 60%. In Sweden an allowable stress of two-thirds of the yield point is tabulated, with weld efficiencies varying from 60% up to 90%. In the Netherlands the same stress is permitted with a weld factor of 100%, provided the calculated extra stress as a result of out-of-roundness of the cylinder is within certain limits. In this code the total stress, being the resultant of the membrane stress and the superimposed stress due to out-of-roundness, has a maximum allowable value, dependent on the yield point. If the stress due to out-of-roundness is large, the membrane stress must be correspondingly the same amount smaller, as the sum of both remains the same.

The result of all these different points of view is that the allowable stresses in pressure vessels vary from about 27% of the yield point up to 66%. It seems reasonable to look again into the matter, to establish which allowable stress and which weld factor can be used.

To avoid making this analysis too complicated, only service temperatures up to about 650° F are considered. The behavior of creep is thus not taken into account.

2. ASSUMPTIONS

It is assumed that rupture occurs as a result of too high a stress or a combination of high stresses in two or three mutually perpendicular directions, or as a result of too high a strain. The true stresses occurring in a vessel are the sum of the so-called membrane stresses, the superimposed stress concentrations and the residual stress. It is a known fact that the magnitude of the residual stress has to be taken into account in the case of brittle rupture at subatmospheric temperatures and in the case of fatigue. It seems to be logical to assume that the residual stress is also important in the case of rupture of a pressure vessel at atmospheric and higher temperatures under static or semistatic loading. The expression "semistatic loading" is used here because an absolute static load does not occur in practice. Very small stress fluctuations will always be present due to what is called, in the Netherlands, "breathing" of the vessel.

Furthermore it is a fact that when rupture occurs in a pressure vessel during service, the appearance of the break is always brittle. A shear fracture has never been found. The following theory of rupture has been largely based on this phenomenon.

3. SIMPLIFICATIONS

To avoid complicating the analysis it is assumed that the material follows Hooke's law up to the yield point and that the amount of yielding which occurs is so small that no strain hardening takes place. In this case the stress-strain diagram has the form shown in Fig. 1. This assumption is not true for austenitic steels and nonferrous metals. For such materials another more complicated calculation has to be carried out, which can be done according to the same principle.

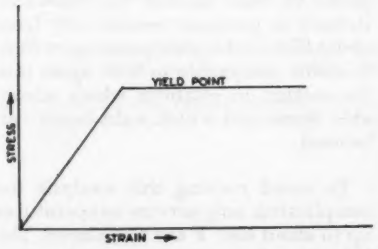

Fig. 1. Simplified stress-strain curve.

A second simplification has been made, assuming that the yield point of the weld is the same as that of the base metal. If necessary, the higher yield point of the weld can be taken into account but for a first attempt to show what happens in a pressure vessel wall, this complication seems unnecessary.

The third simplification is the assumption that if the state of stress is diaxial, yielding occurs when the maximum stress reaches the yield point of the tensile test. It is known that this is not quite true, but the difference as compared with the true behavior is small and, if necessary, this method of calculation can also be refined.

However, since on the following pages the calculations are only used to compare various requirements in the codes, a more accurate analysis is not necessary. For comparison only the above simplifications can be fully accepted.

4. STRESS CONCENTRATIONS

It is mentioned that stress concentrations have to be taken into account. Under the heading of stress concentrations are considered all stresses non-uniformly distributed over the plate thickness, and which have to be superimposed on the membrane stresses, except residual stresses. These stress concentrations can be subdivided into two groups

(*a*) Stress concentrations caused by bending, acting in, at most, two mutually perpendicular directions: According to the simplification accepted above, these stresses cause yielding when the highest value of the stress reaches the yield point of the material in uniaxial tension. The magnitude of these stress concentrations is a function of the membrane stress or of the internal pressure of the vessel.

The stresses are limited by the yield point of the metal. When the vessel wall yields over the whole thickness the stress concentration has vanished totally. Figure 2 shows such a stress concentration combined with a membrane stress, Fig. 2(*a*) in the elastic state, Fig. 2(*b*) when yielding occurs partially and Fig. 2(*c*) when yielding occurs over the whole thickness of the wall.

The magnitude of these stress concentrations varies always to a great extent along at least two mutually perpendicular directions.

Stresses due to out-of-roundness of the cylinder and extra bending stresses in domed ends belong to this type, provided the wall is not too thick. In thick-walled vessels the state of stress is triaxial. This entails that the above-mentioned simplification, that yielding occurs when the maximum stress is equal to the yield point, does not even approximately hold. Furthermore,

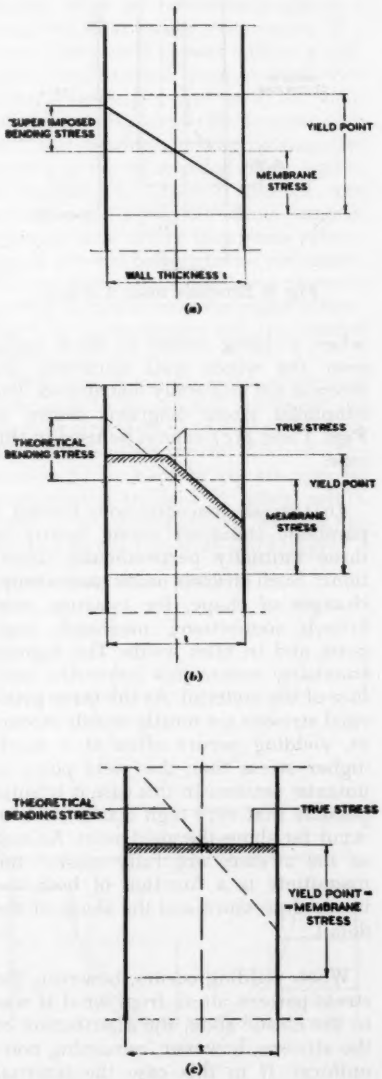

Fig. 2. The influence of the yield point on the stress distribution.

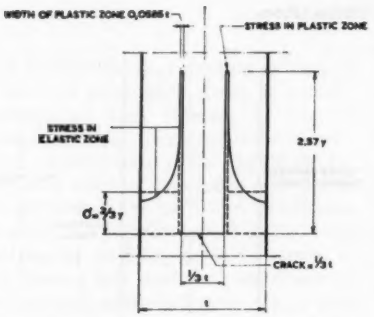

Fig. 3. Stresses near a crack.

when yielding occurs in thick walls, over the whole wall thickness, the stress is not uniformly distributed. The simplified stress diagrams shown in Figs. 1 and 2(c) cannot be used in this case.

(*b*) Stress concentrations having a parabolic character acting mostly in three mutually perpendicular directions: Such stresses occur near abrupt changes of shape, for instance near branch connections, manholes, supports and in fillet welds. The highest triaxiality occurs just below the surface of the material. As the three principal stresses are mostly tensile stresses, yielding occurs often at a much higher stress than the yield point in uniaxial tension. In this case it is quite possible that very high elastic stresses occur far above the yield point. As long as the stresses are fully elastic, the magnitude is a function of both the internal pressure and the shape of the detail.

When yielding occurs, however, the stress pattern alters from what it was in the elastic state, the distribution of the stresses, however, remaining nonuniform. If in this case the internal pressure is relatively low, yielding occurs over a small part of the material; if the internal pressure is relatively high, a greater amount of material yields. The magnitude of the maximum stress, however, remains about the same in both cases. When yielding occurs, the maximum stress is thus only dependent on the shape of the detail and nearly independent of the internal pressure.

An extreme example is formed by the stresses near a crack. Such stresses always reach a magnitude of 2.5 to 3 times the yield point, even if the load is very low.

Figure 3 shows the result of the calculation of the stresses around a crack having a width of one-third of the plate thickness *t*. The allowable membrane stress in the plate without cracks is assumed to be two-thirds of the yield point ($\frac{2}{3}Y$). The stress near the crack is 2.57*Y*. The plastic zone is very small (0.585*t*). If an allowable stress of 0.3*Y* were taken into account, the stress pattern should be the same. In this case the width of the plastic zone should be 0.022*t*.

It is quite possible that the internal stresses due to welding near such details are also triaxial. As a result of the triaxiality it may be very difficult, if not impossible, to relieve these stresses by heat treatment or other methods.

The stresses mentioned under *b* can only be very high as a result of bad design, bad manufacture and/or bad inspection (cracks). If the high stresses exist, however, they are nearly independent of the internal pressure, or of the magnitude of the theoretical allowable membrane stress.

Assuming initially that design and manufacture are satisfactory, only stress concentrations mentioned under (*a*) have to be considered.

5. RESIDUAL STRESSES

When residual stresses in a non-stress-relieved weld are calculated or measured in a direction either parallel or perpendicular to the weld, at some places values up to the yield point are always found. Such a high stress value has to be taken into account in the following analysis.

Recent measurements on nonwelded plates have shown that due to rolling and especially due to a nonuniform cooling down after rolling, residual stresses up to the yield point also occur. The high residual stress is thus not only caused by the welding but always exists in the plate, provided no stress relieving has been carried out.

Welded vessels are often stress relieved at 1200° F. After this stress relieving the residual stress cannot be much lower than the yield point at 1200° F. It has been proved by measurements that after stress relieving a small residual stress always remains, also because of the fact that a uniform cooling down is impossible. This is the reason why in normalized plates a small residual stress also occurs. If a normalized plate is bent cold to a cylinder, or flattened, it is obvious that again a residual stress up to the yield point has to be taken into account. The fact that the high residual stress also occurs in the nonwelded plate, makes a comparison between riveted and welded vessels possible. Many years of practice have shown that stress relieving of riveted boilers is not necessary. As the above considerations show, it is very doubtful whether stress relieving has to be carried out for welded vessels.

The sum of all the residual stresses distributed over a cross section of the plate or structure must always be zero. This implies that tensile stresses have always to be kept in equilibrium by compressive stresses at other points. This is very important, as will be proved in the following paragraph.

6. THE INFLUENCE OF EXTERNAL LOAD ON RESIDUAL STRESSES

To simplify the following analysis it is assumed that for relatively thin plates the residual stresses vary only in the plane of the plate, but remain constant over the plate thickness. This is of course not quite true, but it does not alter the total result of the following considerations very much.

Figure 4(*a*) shows an arbitrray curve of residual stresses along a weld or other section of the base material. In accordance with the law of equilibrium the area above the zero line must be equal to the one below the zero line. On the planes *ab* and *cd* the yield point Y has been reached.

Suppose this plate is now loaded by a uniform stress "σ" smaller than the yield point of the material, shown in Fig. 4(*b*). This stress has to be superimposed on the original residual stress, giving a total stress as shown in Fig.

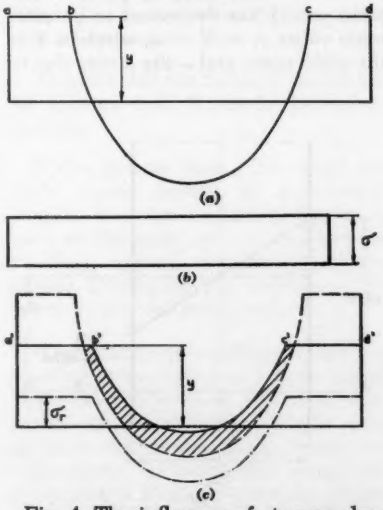

Fig. 4. The influence of stresses due to external load on the residual stresses.

4(c) with a dotted line. It is, however, impossible that the stresses along the lines *ab* and *cd* are above the yield point and the only possibility is that the new stress follows the solid line *a'b'c'd'*. In accordance with the law of equilibrium again the area above the lines *a'b'* and *c'd'* must be equal to the hatched area below. It is true that further yielding occurs locally along the lines *a'b'* and *c'd'*. Between *b'* and *c'*, however, the stresses are fully elastic. This is the reason why the local yielding causes a deformation only slightly larger than that in the elastic state of stress. The accepted simplification that the deformation above the yield point is always small so that strain hardening can be neglected is herewith justified.

During the relief of the external load the material behaves completely elastically, this having been proved by many tests. After relieving, the stress shown with a dot-dash line remains. It is obvious that the original maximum residual stress (equal to the yield point) has decreased to an ultimate value $\sigma_r = Y - \sigma$, wherein Y is the yield point and σ the stress due to the external load. Consider now a single spot of the plate or the weld where the original residual stress is equal to the yield point of the material. The plate is now loaded with a uniformly distributed membrane stress and a superimposed stress concentration of the bending type as described in Section 4 (*a*). This total stress is a function of the membrane stress σ_m and can be written as $C\sigma_m$, wherein C is the stress concentration factor. The stress distribution over the plate thickness, supposing that Hooke's law is followed, is shown in Fig. 5(*a*). On the left the stress is $C\sigma_m$, in the heart of the plate σ_m, while the stress on the right is $(2 - C)\sigma_m$. These stresses have to be superimposed on the residual stresses. As locally the plate is loaded to the yield point by these residual stresses, no further increase of stresses is possible at these spots. If now the internal pressure is relieved, the stresses shown on Fig. 5(*a*) have to be subtracted from the existing stress, being the yield point. The remaining residual stress is $Y - C\sigma_m$ at the left side of the plate, $Y - \sigma_m$ in the heart of the plate and $Y - (2 - C)\sigma_m$ at the right side of the plate. See Fig. 5(*b*).

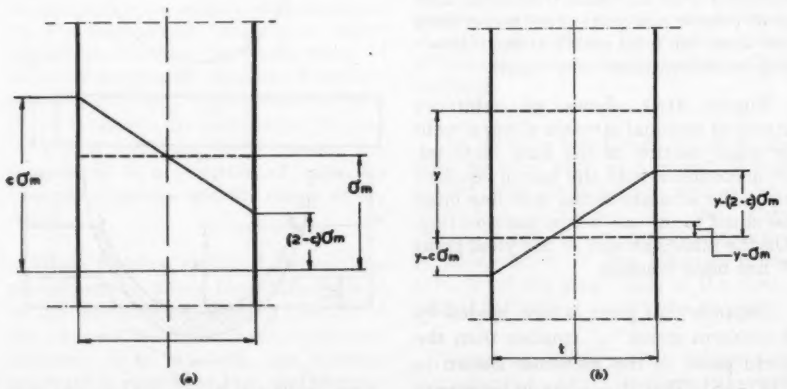

Fig. 5 Theoretical stress distribution over the plate thickness and ultimate residual stresses.

These ultimate residual stresses have to be taken into account.

It does not matter at all whether the maximum stress $C\sigma_m$ is above the yield point or not. During stress relieving the material behaves elastically as long as $Y - C\sigma_m \geq -Y$. In this case the ultimate residual stress never reaches the yield point in compression. Should the yield point in compression have been reached, the stress during loading and unloading would vary from the positive to the negative yield point, which is known to provoke a rupture after few cycles.

From the above equation it follows that $C \leq 2Y/\sigma_m$. It will be shown on the following pages that the factor C must be smaller for other purposes. The yield point in compression is thus never reached; the total strain of the material is limited in such a way that no rupture is to be expected.

7. THE INFLUENCE OF THE HYDROSTATIC TEST PRESSURE FOLLOWED BY RELOADING AGAIN TO THE WORKING PRESSURE AT ATMOSPHERIC TEMPERATURE

The membrane stress due to the hydrostatic test pressure must be below the yield point. Otherwise unpermissible deformation occurs during the test. According to the previous considerations the largest ultimate residual stress after hydrostatic testing is $\sigma_r = Y - (2 - C)\ \sigma_t$, wherein σ_t is the membrane stress during the test. When loading the vessel to the membrane working stress σ_m, the total maximum stress is (see Fig. 6 on the right):

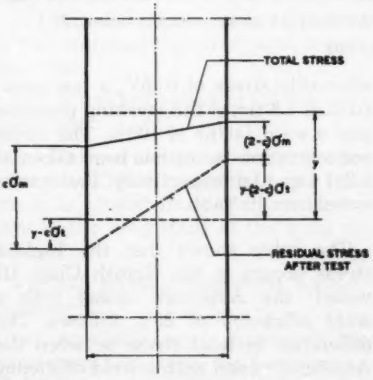

Fig. 6. Total stresses if residual stress is equal to the yield point.

$$\sigma_{tot} = \sigma_r + (2 - C)\sigma_m$$

or

$$\sigma_{tot} = Y - (\sigma_t - \sigma_m)\ (2 - C)$$

The total stress is smaller than the yield point if $\sigma_t > \sigma_m$ and $2 > C$. It follows, therefore, that the test pressure should always be higher than the working pressure, while on the other hand the stress concentration factor should be smaller than 2.

The fact that the factor C should not be greater than 2 can be proved as follows:

If C is greater than 2 the vessel will yield again locally at a pressure smaller than the working pressure. As soon as the yield point is reached the bending moment cannot further increase. During further increase of the pressure the following occurs.

It was already mentioned that the bending stress varies to a great extent along the wall surface. The yield point is thus only reached very locally, other spots in the surroundings remaining fully elastic. As soon as the yield point is reached a small deformation occurs. This deformation, however, must also be very local and therefore can never

be large, as large deformation is prevented by the fully elastic surroundings. During a further increase of pressure the greater part of the resultant bending moment is taken up by the surroundings, only a very small part being relaxed by the local deformation. The extra stress in the surroundings therefore increases more than proportionally to the internal pressure. During the relief of the pressure there is a certain instant when the total bending stresses can again be taken up by the formerly highly loaded spot. When loading again takes place the factor C is very slightly smaller than originally, due to the small deformation. It is, however, quite possible that every time the vessel is reloaded in service, a small local deformation occurs until the sum of all deformations together has become so large that the surroundings need no longer take any extra stress.

Fatigue test pieces subject to such high fluctuating loads have shown that, due to the fact that every time the maximum stress occurs, a small deformation is caused; rupture occurs after a very short number of stress variations. To be thus absolutely sure that the local deformation occurs only once during the hydrostatic test, the stress concentration factor should be limited to the value "2." In this case it is absolutely certain that no rupture will occur as a result of too high a strain during the starting-up periods.

A small local strain resulting in a small relaxation of the stress concentration factor also occurs when the vessel is loaded for the first time to the hydrostatic test pressure. Due to this strain the new stress concentration factor, when loading again to the working pressure, is always slightly smaller than used in the calculation. The total stress thus remains always below the yield if C is limited to "2".

The fact that the above formula gives a somewhat higher stress than that which actually occurs does not influence the results shown below, because of the fact that the equation is only used for comparison of different calculation methods. In this case all the calculated stresses are slightly on the high side.

8. COMPARISON OF VARIOUS METHODS OF CALCULATION AND CONCLUSIONS FOR VESSELS NONSTRESS RELIEVED BY HEAT TREATMENT AT ATMOSPHERIC WORKING TEMPERATURE

According to the American and the British codes a minimum safety factor of 4 to the tensile strength is permitted. The allowable stress for carbon steel is then about 0.45 Y. In the U. S. a weld efficiency of 90% is required for a radiographed nonstress-relieved weld and 80% for a nonradiographed, nonstress-relieved one. In Great Britain a nonradiographed, nonstress-relieved weld for a Class III vessel has a weld efficiency of maximum about 60%. The test pressure for all these vessels is 1.5 times the working pressure. All these requirements are now compared with a non stress-relieved vessel with an allowable stress of $0.66Y$, a test pressure of 1.3 times the working pressure and a weld factor of 100%. The stress concentration factor has been taken as 1.2, 1.4 and 1.6 respectively. The results are shown in Table 1.

The table shows that the highest stress occurs in the British Class III vessel; the American vessel with a weld efficiency of 80% follows. The difference in total stress between the American vessel with a weld efficiency of 90% and the vessel with a weld efficiency of 100% but with a 1.63 times higher allowable membrane stress is

TABLE 1

TOTAL STRESS IN VARIOUS NONSTRESS-RELIEVED VESELS AT ROOM TEMPERATURE

Tabulated allowable membrane stress	0.450Y	0.450Y	0.450Y	0.660Y
Weld efficiency	90	80	60	100
Allowable membrane stress in weld	0.405Y	0.360Y	0.270Y	0.660Y
Stress during hydrostatic test	0.608Y	0.540Y	0.405Y	0.858Y
Total stress for C=1.2	0.838Y	0.856Y	0.892Y	0.842Y
Total stress for C=1.4	0.878Y	0.892Y	0.919Y	0.882Y
Total stress for C=1.6	0.919Y	0.928Y	0.946Y	0.921Y

negligible. Compared with the Class III vessel a 2.44 times higher membrane stress is permissible without increasing the true total stresses occurring.

It is known that the first three vessels mentioned in the table have proved to be completely safe. According to the same table there is no reason to believe that the last vessel is less safe. The high allowable membrane stress has been adopted in the Swedish, Italian and German codes on the basis of 15 years of experience. A weld efficiency of 100% is to be adopted in the new Netherlands Code, with the same allowable stresses.

From these considerations the following conclusions can be drawn:

(a) An allowable membrane stress of two-thirds of the yield point is permissible.

(b) A weld efficiency of 100% is permissible.

(c) The use of other weld efficiencies lower than 100% is pointless; the total stress is almost completely independent of the magnitude of the weld efficiency.

Further equally important conclusions are:

(d) As all the vessels shown in Table 1 have worked safely for many years, all loaded to about the same stress, the high calculated total stress can never be the criterion for rupture. This stress must be safe. Rupture, therefore, can only occur as a result of stress concentrations mentioned in Section 4 *(b)*. These stress concentrations have not been taken into account up to now.

(e) In Section 7 it was proved that a stress concentration factor of 2 should do no harm during the starting-up periods. Comparison with existing practice shows that this value cannot be dangerous during service, either. Flat end plates, stayed flat walls, flanges, etc., are subject to pure bending. At some spots in such plates the original residual stress will also reach the yield point. If for these parts similar considerations are carried out as done

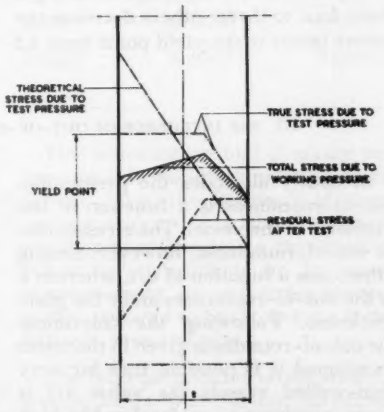
THEORETICAL STRESS DUE TO TEST PRESSURE
TRUE STRESS DUE TO TEST PRESSURE
TOTAL STRESS DUE TO WORKING PRESSURE
YIELD POINT
RESIDUAL STRESS AFTER TEST

Fig. 7. Total stress if residual stress is zero

for parts loaded by a membrane stress with superimposed bending stress, it will be found that no stress relaxation as a result of hydrostatic testing is possible, as will be shown in Section 11. This entails that these spots are always loaded to the yield point. As these flat plates, however, do not rupture during service it follows that stresses up to the yield point are permissible, i. e., that C may be equal to 2. From these considerations the conclusion can be drawn that the permissible stress concentrations are proportional and at most equal to the permissible membrane stresses, that is to say that C is limited to the maximum value "2" independent of the magnitude of the allowable membrane stress.

All the above conclusions are based on the fact that at some points in the plate or the weld the residual stress is equal to the yield point in tension. There are also other places where the residual stress is negligible or equal to the yield point in compression. Figures 7 and 8 shows the total stresses in both cases, for a membrane stress of $0.66Y$, $C=2$ and a test pressure of 1.3 times the working pressure. Here, too, the stresses never exceed the yield point, either in tension or in compression.

9. THE CALCULATION OF DOMED ENDS

The stress concentrations so far under consideration occur also in domed ends, conical ends, etc. In some codes only the membrane stresses are taken into account, the bending stresses being neglected or kept below certain values by limiting the knuckle radius. Other codes take the total stress into account, but decrease the safety factor to the tensile strength from four to three; others decrease the safety factor to the yield point from 1.5 to 1.1. Previous considerations have shown that all these methods are more or less arbitrary.

In accordance with the above considerations it is possible to adopt the recommended high membrane stress, 66% of the yield point, and to limit the superimposed bending stresses to the same value. Following this method the minimum height of the dome or the minimum knuckle radius can be calculated.

10. THE INFLUENCE OF OUT-OF-ROUNDNESS, MISALIGNMENT, ETC.

In nearly all codes the permissible out-of-roundness is a function of the diameter of the vessel. The stresses due to out-of-roundness, however, among others are a function of a/t, wherein a is the out-of-roundness and t the plate thickness. Following the tolerances for out-of-roundness given in the codes mentioned it is possible that for very thin-walled vessels the value a/t is large, resulting in an intolerably high stress due to out-of-roundness.

The high allowable stresses mentioned according to the new Netherlands code, combined with a weld efficiency of 100%, may only be adhered to provided the stresses due to out-of-roundness are kept within certain limits. The procedure followed in this code can be described as follows:

The total theoretically allowable stress is 90% of the yield point. This

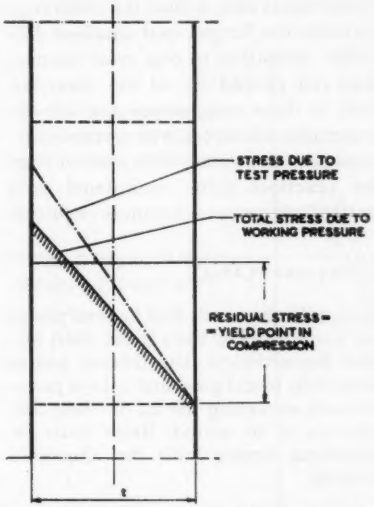

Fig. 8 Total stress if residual stress is equal to yield point in compression

stress, however, has to be reduced, for nonstress relieving. The total stress now permitted in the vessel, being the sum of the membrane stress and the stress due to out-of-roundness, shall not exceed the above-mentioned reduced stress. This method is illustrated in the following example. To make a comparison possible with the stresses shown in Table 1, the original Netherlands data are modified slightly. This, however, does not alter the principle.

For the example it is assumed that the allowable reduced stress, being 90% of the yield point minus 0.108Y for nonstress relieving, is 0.792Y. This stress is thus equal to $C\sigma_m$. The permissible membrane stress is now $0.792Y/C$, resulting in 0.660Y, 0.566Y and 0.496Y for a stress concentration factor C = 1.2, 1.4 and 1.6 respectively. The test pressure is kept at 1.3 times the working pressure. The result is shown in Table 2.

TABLE 2—INFLUENCE OF OUT-OF-ROUNDNESS

Stress concentartion factor	1.2	1.4	1.6
Allowable stress	0.660Y	0.566Y	0.496Y
Stress during hydrostatic test ..	0.858Y	0.737Y	0.648Y
Total stress	0.842Y	0.898Y	0.940Y

Compared with the last column of Table 1 it is evident that the total stresses have increased slightly. However, if the stress concentration factor due to out-of-roundness is greater than 1.2 the permissible membrane stresses are smaller and the wall thickness greater, compared with those in Table 1. The total stress, however, remains about the same.

It thus seems that the influence of the out-of-roundness is overestimated in the Netherlands code.

The following method of taking into account of out-of-roundness seems logical. First, the influence of stress concentrations due to the permissible misalignment has to be investigated, either by calculation or by stress measurements; say this stress concentration is found to be C_1, being a factor between zero and one.

The total permissible stress concentration factor is 2. For out-of-roundness there remains now only a factor $2 - C_1$. With the aid of this factor the

permissible out-of-roundness can be calculated, it being a function of a/t and of the internal pressure. In nearly all cases, except for very thin-walled vessels, the thus calculated permissible out-of-roundness will be much greater than that permitted for practical reasons. A normal practical value for limiting the out-of-roundness, accepted in nearly all codes, except the Netherlands one, is that the difference between the largest and smallest diameter, measured in one cross section, shall not exceed 1% of the diameter. Only in those cases where the out-of-roundness calculated with a stress concentration factor $2 - C_1$ is smaller than the practical value mentioned is a smaller tolerance on ovalness required.

11. THE CALCULATION OF FLAT-END PLATES

Years ago very thin flat-end plates were designed without any calculation or with the aid of a very simple calculation. In the last few years better calculation methods have been developed, with the result that flat end plates are much thicker than those used before. Nevertheless, the thinner plates have been found good and safe in practice and, assuming the up-to-date calculation to be sound, there must be something wrong with the allowable stresses.

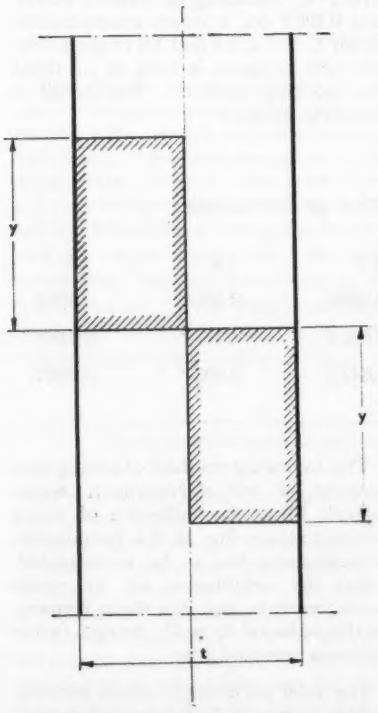

Fig. 9 Bending stresses when the plate is loaded totally above the yield point

In flat-end plates no membrane stress exists. The stresses occurring are of the pure bending type. For the membrane stress an allowable value of 66% of the yield point is permissible. Supposing 100% of the yield point had been allowed, the vessel wall should always yield over the whole thickness. The allowable stress is thus 66% of that which causes yielding over the whole wall thickness. When pure bending stresses occur the plate yields over the whole thickness if the diagram has the shape shown in Fig. 9. The moment per unit of plate length is now $M_y = Y(t^2/4)$, wherein Y is the yield point. If now, just in the same manner as was done with the membrane stress, the allowable bending moment is taken as $M = \frac{2}{3} M_y$, the following relation is found

$$M = Y \frac{t^2}{6}$$

The value $t^2/6$ is equal to the section modulus of the plate in the elastic state. From this it follows that the allowable stress in flat-end plates and other plates subject to pure bending is equal

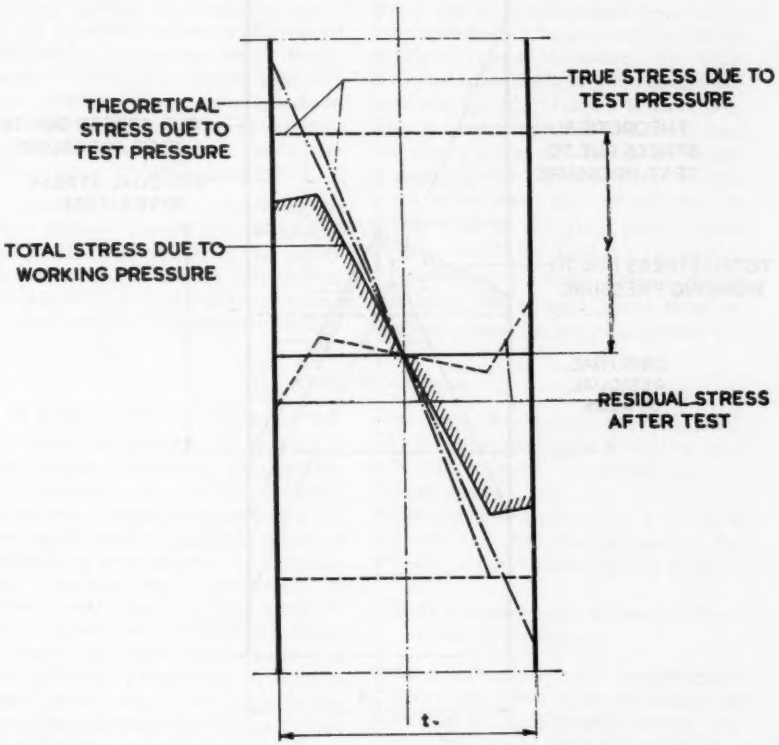
THEORETICAL STRESS DUE TO TEST PRESSURE
TRUE STRESS DUE TO TEST PRESSURE
TOTAL STRESS DUE TO WORKING PRESSURE
RESIDUAL STRESS AFTER TEST
t

Fig. 10 Total stresses in plates subject to pure bending if the original residual stress is zero.

to the yield point of the material. Now the same method has been followed for bending stresses and membrane stresses.

It is interesting to investigate what happens when residual stresses exist in the plate. If the original residual stress is equal to the yield point, in compression or in tension, the total stress always remains equal to the yield point. When a plate having local spots where yielding due to original residual stress occurs is loaded by superimposed bending moments, the extra stress due to bending cannot be taken up by these spots, but other points in the surroundings take the load and are stressed more severely as a result. This is true, independent of the magnitude of the bending stress. It is thus understandable that the third-class vessels, subject to very low bending stresses, are also always loaded to the yield point at certain spots of the plate. This is the reason why in Section 8 the conclusion was accepted that stresses up to the yield point are permissible and cannot do any harm. Figure 10 shows the total stress after hydrostatically testing and reloading to the working pressure in the case where no original residual

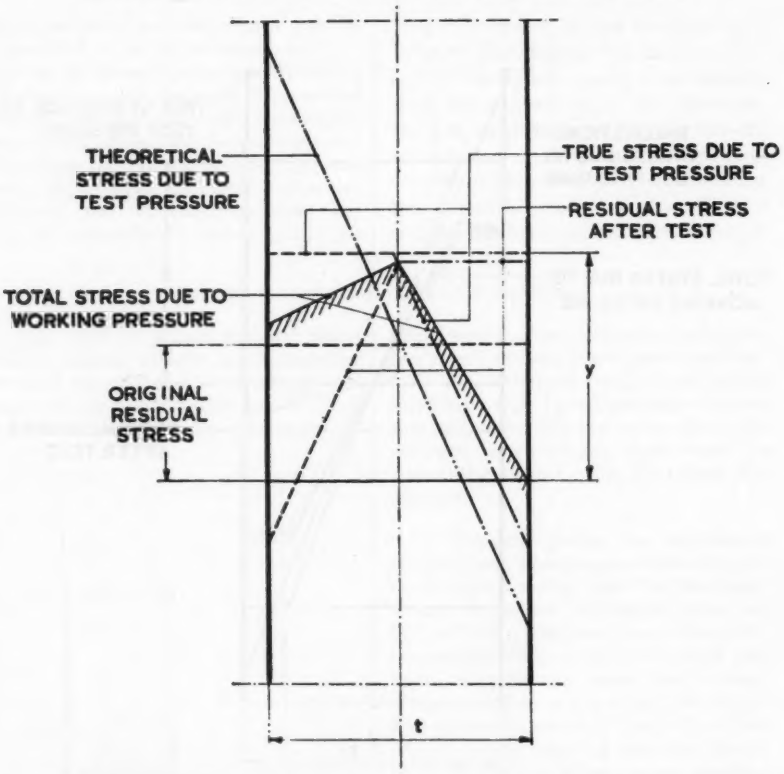

Fig. 11 Total stresses in plates subject to pure bending if the original residual stress is 60% of the yield point.

stress exists. Figure 11 shows the same where the original residual stress is equal to 60% of the yield point. In all these cases the total stress remains below the yield point.

The above considerations prove that the recommended stresses are indeed permissible. Lower allowable bending stresses result locally in the same total stress, this being the yield point.

It is obvious that by following this method the thickness of end plates can be reduced, as mentioned already at the beginning of this paragraph.

12. TESTING TO RUPTURE

Sometimes a vessel is tested to rupture to check the adopted factor of safety. When the calculation has been carried out with a safety factor of 4 and the vessel ruptures at a pressure of four times the working pressure, everything seems satisfactory.

During testing to rupture, however, at a certain pressure the vessel yields totally. In this case such a tremendous deformation occurs that the stress concentrations mentioned in Section 4 *(a)* relax totally. During total yielding the vessel is only loaded by the membrane stresses calculated.

In service, however, the vessel is locally always loaded to about the yield point, independent of the membrane stress used in the calculation. Thus it is obvious that neither the rupture test nor the acceptance of a factor of safety can be relied upon. Furthermore the rupture during the test is nearly always of the shear type, while always in practice a brittle rupture occurs. On the other hand it is quite possible that although a vessel has passed the rupture test satisfactorily, nevertheless a similar vessel in practice ruptures after some time of service. As the loading to the yield point cannot be the reason for rupture (otherwise all nonstress-relieved vessels would fail after some time) there must be another reason for such occurrences.

13. THEORY OF RUPTURE

(a) At Subatomospheric Temperatures

To study the behavior of rupture it is, of course, necessary to examine cases of fracture in practice. At subatmospheric temperatures rupture always has its origin in faults in the weld (cracks, bad penetration, etc.), in the plate (cracks) and sometimes in welded details, such as pipe connections, supports, etc. In Section 4 *(b)* it was mentioned that near cracks and spots with bad penetration a triaxial state of stress occurs, the value of the highest stress being about 2.5 to 3 times the yield point and independent of the load on the vessel (see Fig. 3). In the neighborhood of badly designed or manufactured pipe connections and other details, stress concentrations of the same order may occur.

It is generally accepted that steel has a brittle fracture strength, quite different from the ultimate tensile strength where failure is caused by shear stresses. If the stress value exceeds this brittle fracture strength, rupture starts. This is only possible for relatively low temperatures, below the so-called transition temperature.

Rupture need not start directly after the vessel has been put into service—very often the vessel behaves well in the beginning. After some time, however, age hardening has occurred, which is sometimes just enough to start a brittle rupture. At subatmospheric temperatures only the very high stress concentrations due to faults in the weld or in the plate or due to a bad design are responsible for the rupture.

(b) At Temperatures Above the Transition Temperature

As a subatmospheric temperatures rupture can always be prevented by selecting an appropriate ductile material, this is not always possible in a higher temperature range. To study the behavior of rupture in the latter case, it will be necessary to examine the experience and to investigate the circumstances under which a fracture has occurred.

First of all it is a fact that rupture can occur in vessels calculated with low theoretical stresses as well as in vessels under high theoretical stresses. The rupture seems to be independent of the membrane stresses occurring.

Secondly, a rupture during service has always a brittle appearance. Riveted vessels sometimes show cracks or complete failure after a long period of service. The rupture always occurs

near rivet holes, stay bolts, expanded tubes, etc. Modern stress theories have proved that these spots are subject to very high stress concentrations of the triaxial type, above the yield point, as described in Section 4 *(b)*. An attendant circumstance is that mostly, if these failures occur, the fabrication is so bad that the medium which the vessel contains can penetrate between the riveted plates or into gaps near staybolts, etc. It seems, therefore, that the content of the vessel, even if not corrosive in the common sense of the word, exercises a considerable influence.

If a rupture occurs in a welded vessel, the origin is a crack or other fault in the weld, in the plate or some other spot of high triaxial stress concentration as mentioned in Section 4 *(b)*. Here the danger of rupture is less than for riveted vessels because of the fact that the medium cannot penetrate into a crack, if not situated at the surface of the plate.

The final important point is that, in the beginning of the life of a boiler or pressure vessel, the material is strong enough to withstand this high triaxial stress. The only possibility is that during the life of the vessel the mechanical properties gradually decrease.

In Section 4 *(b)* it was mentioned that if at certain spots a triaxial state of stress occurs and at the same time the material yields, the magnitude of the stresses is practically only a function of the shape and not dependent on the internal pressure. This is the reason that rupture may also occur in vessels calculated with a low allowable membrane stress. An increase in the allowable stresses, as proposed above by accepting a weld efficiency of 100%, can thus be effected without increasing the danger of rupture.

The other facts mentioned can be explained by considering fatigue to be the cause of rupture. The vessel is always semistatically loaded, that is to say that always small stress variations occur. During loading and reloading, a state which occurs several times during the life of the vessel, even very high stress variations occur.

It is a known fact that the fatigue strength decreases to a very great extent if the state of stress is triaxial. This is not the case with statically loaded specimens subject to a triaxial state of stress, which are mostly stronger than specimens under uni- or di-axial tension.

If fatigue tests are carried out with wetted test bars, the life of the specimen is much shorter compared with that of dry test pieces. Herewith the influence of the medium is confirmed.

A rupture as a result of fatigue has a brittle appearance, whereas a rupture as a result of too high a static load is nearly always a shear fracture.

It seems logical to assume that rupture only occurs due to fatigue at spots where the stresses are triaxial. Probably the other parts, where the state of stress is diaxial, can withstand the stress variations mentioned.

As the rupture is connected with a gradual decrease in mechanical properties under the influence of very high stress concentrations, it is obvious that a test to rupture, to check the safety factor, is of no use at all.

It is even doubtful whether the ultimate tensile strength of the material has any importance, except for checking its quality.

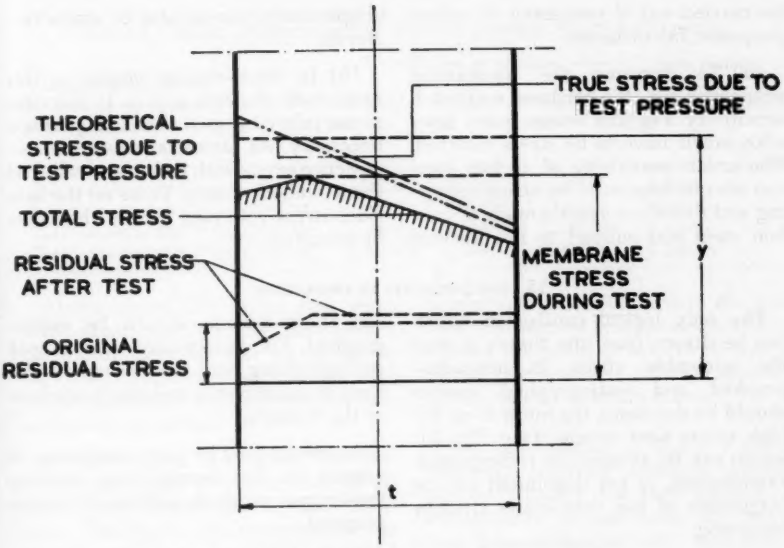

Fig. 12 Total stresses in stress-relieved vessels.

14. STRESS-RELIEVING

Up to now only nonstress-relieved vessels, which always have spots where the residual stress is locally equal to the yield point, have been considered. Due to stress relieving the residual stresses decrease. It seems clear that the residual stress after heat treatment at 1200° F cannot be much lower than the yield point at that temperature. Data collected in the U. S. A. for carbon steel show that the ratio of the yield point at 1200° F to that at atmospheric temperature varied from 0.16 to 0.34. The residual stress is thus at least 0.16Y. Due to nonuniform cooling, however, the residual stress can be much higher.

When the sum of the residual stress after stress relieving and the hydrostatic proof membrane stress is equal to, or above, the yield point at room temperature, the total stresses remain the same as in the nonstress-relieved vessel. This is the case with the recommended hydrostatic test pressure, causing stresses of 0.858Y. In other cases when the allowable stress is, for instance, one quarter of the tensile strength combined with the maximum weld efficiency of 95% or other lower values, the total stresses are lower.

The various calculated stress curves are shown in Fig. 12.

From this consideration it follows that if the allowable stress is not too high, a stress-relieved vessel is possibly subject to a lower stress than a nonstress-relieved one, notwithstanding the fact that the weld efficiency of the latter is lower (often much lower).

As, however, the high total stresses occurring in non-stress-relieved vessels are fully permissible, the expensive heat treatment is not necessary from a mechanical point of view.

Stress-relieving will therefore only

be carried out if necessary for other purposes, for instance:

(a) To improve the mechanical properties, viz., the hardness and notch sensitivity. For this reason many low-alloy steels have to be stress relieved. The notch sensitivity of carbon steel can also be improved by stress relieving and therefore vessels made of carbon steel and subject to low service temperatures should also be stress relieved.

(b) In thick-walled vessels a triaxial state of stress occurs. In this case stress relieving such vessels is perhaps necessary. As far as is known no experience exists with nonstress-relieved thick-walled vessels. To be on the safe side, stress relieving should therefore be required.

15. RADIOGRAPHIC EXAMINATION

The only logical conclusion which can be drawn from the theory is that the allowable stress in nonradiographed and radiographed vessels should be the same, the more so as the high stress near cracks (see Fig. 3), which can be avoided by radiographic examination, is not dependent on the magnitude of the membrane stresses occurring.

If a weld is difficult to make without cracks or other faults developing, radiographing is required. For this reason thick vessels should be radiographed. For thin-walled vessels spot radiographing will be perhaps sufficient to examine the welding procedure or the welders.

As cracks may be very dangerous in vessels for low-temperature service, these apparatuses should also be radiographed.

Only in the case where the duty of the vessel is not severe, so that no explosion occurs as a result of rupture, radiographing may be omitted.

16. VESSELS FOR HIGHER SERVICE TEMPERATURE UP TO 650° F

At increasing temperature, the yield point decreases. Therefore, at higher temperatures the allowable membrane stress should be two-thirds of the yield point at the service temperature of the vessel. The test pressure remains 1.3 times such working pressure as the vessel can withstand at atmospheric temperature, causing a stress of $0.858Y$, because according to the formula the test pressure should be as high as possible.

According to the American and British codes, the allowable stress remains constant up to 650° F. The total stress relative to the hot yield point, however, increases because of the fact that the yield point decreases. At 650° F the hot yield point is about 68% of the yield point at atmospheric temperature. If the stresses are expressed in terms of the hot yield point, the stresses at atmospheric temperature have to be divided by 0.68. Table 3 gives the new stresses at 650° F, relative to the hot yield point Y_h, for nonstress-relieved vessels.

From Table 3 it follows that the lowest total stress occurs in the vessel with the highest allowable stress.

Nearly all the stresses are theoretically above the yield point. This is, of course, impossible in practice. Up to the temperature at which a real yield point exists, which is about 570° F, the material yields during the heating-up period, so that in reality the total stress is equal to the yield point, independent of the membrane stress allowed. This again is a proof that a stress equal to the yield point cannot be dangerous, because it always occurs.

TABLE 3—TOTAL STRESSES AT 650° F IN NONSTRESS-RELIEVED VESSELS

	According to codes			New proposal
Tabulated allowable membrane stress	0.450Y	0.450Y	0.450Y	$0.660Yh=0.450Y$
Weld efficiency	90	80	60	100
Allowable membrane stress in weld	0.405Y	0.360Y	0.270Y	$0.660Yh=0.450Y$
Stress during hydrostatic test	0.608Y	0.540Y	0.405Y	0.858Y
Total stress at 650°F for C=1.20	$1.225Yh$	$1.254Yh$	$1.308Yh$	$0.990Yh$
Total stress at 650°F for C=1.40	$1.285Yh$	$1.308Yh$	$1.346Yh$	$1.150Yh$
Total stress at 650°F for C=1.60	$1.345Yh$	$1.359Yh$	$1.387Yh$	$1.235Yh$

Above about 570° F no real yield point exists; that is to say, instead of a horizontal part in the stress-strain curve only a kink is shown. In this case the simple theory no longer holds good, as mentioned before.

It is, however, a known fact that above about 500° F a relaxation of all statically indeterminate stresses takes place. The higher the temperature the sooner and the more the residual stresses and the bending stresses will decrease. At 650° F, for instance, probably a great many of the residual stresses and bending stresses have relaxed after some time, so that the total stress is not much higher than the yield point. The fact, thus, that above 570° F no real yield point occurs does not mean that no decrease in stress takes place. Stress measurements have proved that the relaxation mentioned does indeed take place. There is thus a good reason to assume that the stress always follows the yield point curve and at higher temperatures follows approximately the 0.2% strain curve.

The last column of Table 3 shows that if the proposed method of calculation is followed, the total stresses at atmospheric temperature are lower than those calculated with other methods, shown in the first three columns. As a relaxation of the stresses must occur, the final stress at the working temperature is reached with less deformation in the vessel which has been calculated as proposed. This is important because the deformation may occur at a temperature where some materials are hot-brittle. The less the deformation is, the less the possibility of strain aging and rupture.

17. GENERAL REMARKS

The recommended allowable stresses may seem very high to more conservative people. Apart from the fact that an attempt has been made to prove that the total stresses are always about the same, independent of the allowable stress used for the calculation, the proposed allowable stress is totally in agreement with common practice.

An allowable membrane stress of two-thirds of the yield point has already been used in some European codes for many years. Such stress values are also permitted for storage tanks, pipes, steel structures and bridges. In the last few years there has even been a tendency to increase the allowable stresses in steel structures to 86% of the yield point. Compared with those stresses the proposed allowable stresses seem to be low. The high allowable bending stresses to be superimposed on the membrane stresses are not higher than normally occurring in pressure vessels.

The allowable pure bending stresses

of 100% of the yield point have already been used by the author and others for many years for the calculation of flat end plates and flanges. Such high stresses have also been allowed for many years in flat tank tops for submarines, etc. Furthermore, as steel structures are calculated according to the theory of plasticity, in a calculation method already used many years before the war with great success in the Netherlands by Professor Kist and others, and in the last few years advocated by Professor Baker in Great Britain, similar bending stresses are permitted.

The only thing that has been done in this report is to try to prove, with a calculation in accordance with the above-mentioned theory of plasticity, that these high stresses are not only permissible, but also that they do not alter the true total stresses occurring.

The recommended weld efficiency of 100% has been in use for many years in steel structures with total success. Here again nothing new has been proposed.

18. CONCLUSIONS

The problem of the stresses occurring in boilers and pressure vessels has been studied with the aid of both the theory of plasticity and the theory of elasticity, taking into account the residual stresses in the weld and in the non-welded plate and the stress-relieving effect of the hydrostatic test.

The calculated maximum total stress occurring is nearly always equal to the yield point of the material and independent of the allowable membrane stress and weld efficiency used for the calculation.

As such a high stress always occurs, it cannot have any influence on the rupture of the vessel. Rupture can only be due to cracks or other faults in manufacture and/or design. Such faults result in stress concentrations far above the yield point. In this case the state of stress is triaxial. It is known that the material only fails as a result of those high stress concentrations.

As the total stress occurring is not dependent on the membrane stress used for calculation, the latter should be as high as possible.

An allowable membrane stress of 66% of the yield point is recommended. The permissible superimposed bending stress can also be 66% of the yield point. In case pure bending stresses exist, the allowable stress can be equal to the yield point.

The test pressure should load the vessel to a stress 1.3 times the allowable membrane stress at atmospheric temperature.

The proposed allowable stress and test pressure limit the deformation of the material in such a way that no rupture can occur due to excessive strain.

The weld efficiency should always be 100%.

The use of a factor of safety is not based on sound reasoning.

Stress relieving is not necessary with a view to strength and should only be carried out for improvement of the mechanical properties of the material and perhaps in the case of very thick shells.

Radiographing should be carried out when a possible rupture would cause an explosion and in all other cases where a rupture is dangerous. In some cases, if the weldability of the material is low, radiographic examination is also required.

Only good design, excellent manufacture and adequate inspection can prevent rupture in service. The allowable stress is far less important and bad design and manufacture can never be compensated by keeping the allowable stress low.

Discussion

by

CAPT. CARL J. LAMB, USNR (R) Inactive

on

MAKE-UP FEED WATER REQUIREMENTS FOR NAVAL VESSELS

By LESLIE E. ALSAGER

It is apparent in this well written article that the Bureau of Ships is maintaining its recognized high standards. Such a statistical analysis of Naval steam plants is indicative of the continuing high order of Naval Engineering.

The curve and equations appear to be ideal for the purpose intended, except for one thing—they do not result in satisfactory performance, when compared with previously proven standards.

When the Light Cruiser *Atlanta* was being built, the Supervisor of Shipbuilding informed the prospective Engineer Officer that, although BuShips design data called for make-up feed water requirements of 4,000 gallons per day, reports from the previous 18 vessels of the class in commission showed an average consumption of 12,000 gallons or more per day. This excessive consumption had the designers, shipbuilders, the Supervisor of Shipbuilding and the Bureau of Ships all worried.

The prospective engineer officer had previously served on the Heavy Cruiser *Vincennes*, and for a year as engineer officer on the Heavy Cruiser *Indianapolis*. On each of these heavy cruisers the average daily make-up feed requirements were around 4,000 gallons per day.

After *Atlanta* went into commission, the make-up feed required for the first week did amount to 12,000 gallons per day. A careful analysis of the plant, and exhaustive inspection soon uncovered the cause. In addition to the five causes of lost steam which Mr. Alsager lists, there are two which he did not list: the laundry and the scullery, both of which use live steam for combined heating and sterilizing. It was found that the standard practice in the scullery, which was operated by a seaman, second class, was to leave the steam valve open 24 hours per day. The A Division Officer was made responsible for keeping the steam valve to the scullery secured at all times except when mess gear was

actually being washed, and for periodic inspections of the Laundry. From that time on the make-up feed requirements on *Atlanta* dropped to an average of less than 4,000 gallons per day, being very close to 3,600 gallons per day.

Based upon the above, and the figure of 813.4 gallons per hour for a carrier, derived by Mr. Alsager in his article, (which amounts to 19,521.6 gallons per day) this discussor worked out the problem of determining the amount of feed water the *Atlanta* would require, according to the curve and equations, using 120,000 shaft horse power total, 56% of that or 67,200 SHP demand, at a steam rate of 6.96 pounds of steam per S.H.P. hour. The answer arrived at was 539.5 gallons per hour of make-up feed required, or 12,948 gallons per day.

Since the figure of 12,948 gallons per day is very close to the figure reported to the prospective Engineer Officer of *Atlanta* as an average for 18 similar cruisers, and what *Atlanta* experienced for a week until inexcusable steam losses in the scullery were stopped, one is apt to conclude that Mr. Alsager's equations are based upon standard operation of Naval Vessels today with the steam valves to the sculleries open 24 hours per day.

It is not believed that there is any justification, ever, for a make-up feed rate of 19,521.6 gallons per day for Light Aircraft Carrier (CVL) or 12,948 gallons per day for a Cruiser. It is doubtful that any real operating engineer, in or out of the Navy, could explain or justify make-up feed requirements of over 4,000 gallons per day for a Cruiser or over 6,000 gallons per day for a CVL. It would seem most constructive, if the Bureau of Ships desires to present data to spur Naval operating Engineers to meet or approach ideal performance, that the constants in the equations be adjusted so that when the figures are applied for individual ships, the answer will represent what is attainable in accordance with the design.

Review

of

PRINCIPLES OF ENGINEERING THERMODYNAMICS

Second Edition

KIEFER, KINNEY and STUART

(John Wiley & Sons, Inc., 1954, $7.75)

Reviewed by Associate Professor A. E. BOCK, Department of Marine Engineering, U. S. Naval Academy

While retaining many of the characteristics which made the first edition of this work so outstanding in its field, this second edition has been completely rewritten. Such essential distinctions as those between stored and transient forms of energy, kinetic energy and flow work, units and fundamental dimensions, and between the various systems of units are introduced early and treated thoroughly.

The general plan of the book divides it into four main parts. Part I deals with energy, its classification and accounting. Stored energy, energy in transition as heat or mechanical work, thermodynamic systems, states and properties, and applications of the steady-flow energy equation are included. Highlights of this portion of the work are applications of the energy equation to multiple-fluid systems, chemical process reactions wherein transformations occur, not only in the state of the materials, but in the materials as well, and to semi-flow processes.

Part II, entitled "the Availability of Energy" develops the reversibility aspect of idealized processes and heat engine cycles, following with the Carnot cycle and Carnot Principle. Having established the concept of reversibility, a thermodynamic temperature scale is developed and the efficiency and performance characteristics of Carnot engine and pump cycles are analyzed. Concluding this part is an extensive treatment of the entropy of energy, entropy as a theromdynamic property, general expressions for entropy change, the second law of thermodynamics, the third law of thermodynamics and the Darrieus or "availability function." Helmholtz and Gibbs functions expressing energy relations for chemical and electro-chemical processes, non-flow at constant volume and temperature and steady-flow at constant pressure and temperature, respectively, are described, as well as several Maxwell relations for expressing entropy change as a function of other fluid properties.

Part III concerns the properties and property relations of various working fluids, treating first the solid, liquid, and vapor states, then the ideal gases, next the low pressure gases and gas vapor mixtuers and, finally, the non-ideal gases and vapors.

The general nature of fuels and their combustion along with energy balances, heating values of fuels, chemical equilibrium in combustion, and "rich mixture" and "lean mixture" combustion complete the material constituting Part III.

Engineering applications of the foregoing developments are treated in Part IV. Included among these applications are power generation cycles with condensing and non-condensing fluids, heat pump and refrigeration cycles and the flow of compressible fluids through metering instruments, nozzles and constant-area channels. A chapter on dynamic forces as applied to turbine and compressor blading, characteristics of impulse and reaction blading, and thrust developed by a thermal jet complete the applications.

In developing the quantitative and qualitative aspects of energy and energy transformations, the authors adhere strictly to their objective of placing primary emphasis on the fundamental principles. To this end ideal situations are proposed and thoroughly analyzed, after which the effects of friction are introduced and specific changes noted. Introduction of the second and third laws of thermodynamics is accomplished in a manner which gives unusual clarity to a somewhat abstract, and often mystifying, concept to the student.

Material in Part III, concerning properties and property relations of the various classes of working substances is notable in general for its completeness and extent. Noteworthy is the treatment of specific heats and specific heat changes, and of gas-vapor mixtures, including a multipressure hygrometric chart of wide capability for air and water-vapor mixtures, an enthalpy-mixture ratio graph for humid-air mixtures, and analyses of several thermodynamic aspects of the atmosphere.

The engineering applications are characterized by careful attention to energy balances, availability accountings and thorough analyses of results caused by changing conditions imposed on the cycle or system. Flow of compressible fluids includes a new flow chart for adiabatic flow of ideal gases which greatly facilitates calculations of this nature.

It is evident that great care has been exercised to express each thought and concept in precise and exact terminology. In some cases this involves qualifications which, to the uninitiated, may seem unnecessary, but are, in fact, absolutely essential. The copious use of graphs, tables and diagrams to supplement equations and concepts and to aid in solution of problems is an outstanding feature. Many example problems with their solutions are included, as well as a considerable number of study problems at the end of each chapter, some with answers given and some without.

As expressed by the authors in the preface to this second edition, certain of the material presented goes well beyond the level of the undergraduate student of thermodynamics. However, by a careful selection of topics this book might very well be used for an undergraduate course in the subject. In this respect it might be pointed out that the student would have not only a precisly worded and carefully written text, but an excellent reference book for any later work in fluid mechanics or thermodynamics.

CHANGES IN MEMBERSHIP

The Society takes much pleasure in announcing that the following have joined the society since the publication of the August, 1954, issue of the JOURNAL:

NAVAL

Beebe-Center John G., Jr., Lieutenant, jg, USCG,
Student, MIT, Cambridge, Mass.
Mail: 120 Puritan Road, Swampscott, Mass.

Cameron, Allan Kenzie, Jr., Lieutenant, jg, USN,
3461 So. Sycamore Ave., Los Angeles 16, Calif.

Clabeaux, Theodore Lee, Ensign, USN,
USS BRUSH (DD 765),
% Fleet P.O., New York, N.Y.

Daniell, John Roach, Lieutenant, USCGR,
Realtor & General Contractor,
12021 S. W. Arrago Drive, Santa Ana, Calif.

Eldredge, R. M., Commander, USNR,
Naval Base, Quarters W., Charleston, S.C.

Glenn, Frederick Warren, Lieutenant jg, USNR,
Engineer, Lykes Bros. S.S. Co.
Mail: 436 Main St., Tell City, Indiana

Irwin, Ralph A., Lieutenant Commander, USNR,
Asst. Manager, Aviation Dept., Westinghouse Electric Corp.,
1625 K St., NW., Washington 6, D.C.

Koett, John Robert, Lieutenant, jg, USNR,
Marine Engineer, 2730 Kerekoff, San Pedro, Calif.

Roller, Henry Charles, Lieutenant, jg, USNR,
134 Ohlson Ave., Nutley 10, N.J.

Satterfield, Herschel Earnest, Sr., Commander, USNR,
Electronic Engineer, Development Cont. Dept., Insptr. of Naval Material,
San Francisco, Calif.
Mail: 644 Niantic Ave., Daly City, Calif.

White, Francis Everett, Lieutenant, USNR,
Rep. Allis Chalmers Mfg. Co., Wyatt Bldg.,
777 14th St., N.W., Washington, D.C.

CIVIL

Byrne, Herbert F., General Manager, Production Planning,
U.S. Steel Corp., 525 William Penn Place, Pittsburgh, Pa.

Chmura, Longen John, Leading Electrical Design Engineer,
Electrical Design Div., Design Dept., Electric Boat Div.
Mail: 34 Deane St., Groton, Conn.

Doremus, Edward Peter, Partner, Cathodic Protection Service,
4601 Stanford, Houston 5, Texas

Jackson, Carey B., Director of Research
Callery Chemical Co., Callery, Pa.

Kahlenberg, William John, Vice President,
Kahlenberg Bros. Co., Two Rivers, Wis.
Mail: 2522 Washington St., Two Rivers, Wis.

Reed, R. Stanley, Application Engineering Manager
Star-Kimble Motor Div. Miehle Printing Press & Mfg. Co.,
200 Bloomfield Ave., Bloomfield, N.J.

Sutherland, Donald A., Sales Manager, Star-Kimble Motor Div.
Miehle Printing Press & Mfg. Co.
200 Bloomfield Ave., Bloomfield, N.J.

ASSOCIATE

Calderon, Gonzalo, Lieutenant Commander, B. S.
P. O. Box 3604, Guayaquil, Ecuador

Gavin, William Gilfillan, Captain, Corps of Engrs., USAR,
Sales Engineer, Consultants & Designers, Inc.
Mail: 5903, Brunswick, Va.

Grant, Walter, Executive Assistant, Rheem Mfg. Co.
Mail: 11711 Woodruff Ave., Downey, Calif.

Hume, George, Executive Vice President,
General Engineering & Sales Co., Folger Bldg.
723 15th St., NW., Washington 5, D.C.

Kent, Sherman Crane, Equipment Engineer,
Knolls Atomic Power Laboratory, General Electric Co.
Mail: 2166C, Daise Lane, Schenectady, N.Y.

Levine, George, Electronics Engineer, Bureau of Ships, Navy Dept.
Mail: 8002 Eastern Drive, Apt. 301, Silver Spring, Md.

Pharmer, William Louis, Asst. Sales Manager, Star-Kimble
Motor Div. Miehle Printing Press & Mfg. Co.
200 Bloomfield Ave., Bloomfield, N.J.

Pinkerton, Charles Walter, Government Representative
Lukens Steel Co., Coatesville, Pa.

Porritt, William Athol, Marine Surveyor, American Bureau of Shipping,
45 Broad St., New York 4, N.Y.
Mail: 457 68th St., Brooklyn 20, N.Y.

Schechter, William Howard, Project Supervisor,
Callery Chemical Co.
Mail: RD 1, Zelienople, Pa.

Seel, Carl P., Jr., Marine Sales Engineer, Star-Kimble
Motor Div., Miehle Printing Press & Mfg. Co.
Mail: 36 A, Brookdale Gardens, Bloomfield, N.J.

Werner, Robert C., Project Supervisor, Mine Safety
Appliances Co., Callery Plant, Callery, Pa.

Wright Spencer H. Engineer General Engineering & Sales Co.,
Folger Bldg., 723 15th St., Washington 5, D.C.

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Atwood, Lewis J., Naval Member.

Hoffman, Charles E., Naval Member.

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Spencer, Hugh H., Civil Member.

DIED

Notice has been received with genuine regret of the following deaths of members since the publication of the August, 1954, Journal:

BURKHARDT, JOHN E., Civil Member

SMULLEN, WILLIAM JAMES, Associate Member

CURTIN, J. F., Naval Member

GUARD, JOSEPH A., Naval Member

ASSOCIATION NOTES

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The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. Include on a separate page a short biographical sketch(es) of the author(s). 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

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Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

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NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

Shown below is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine dignified insignia. It is one-half inch in diameter.

The oak leaves and lettering are red on a gold background.

It is available to all members at fifty cents (50c) each.

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